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TONY HALLAS

ON THE COVER

The universe, at least 93 billion light-years across, is awash in some 100 billion galaxies like NGC 6946, a beautiful face-on spiral.

FEATURES

COLUMNS

QUANTUM GRAVITY

IN EVERY ISSUE

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Blogs from the Local Group
Insight from the editors

The Sky this Week
A daily digest of celestial events

Reader Photo Gallery
Share your astroimaging efforts

50 Weirdest Objects
Explore the most curious cosmic oddities

BY DAVID J. EICHER

The end of everything

This special issue of *Astronomy* has been a long time coming. Delivering stories that address the cosmic distance scale, the incredibly large size of the universe, has been a topic our editors have planned for some time.

While we can all appreciate the immense size of it all, cosmic evolution brings up a related topic: What is the fate of the universe?

This elegant question is not an easy one to answer. We know that as we look out in space, we're looking back in time. The distant universe is a snapshot of what existed billions of years ago, and we do not have an accurate picture of many of the objects we see as they really are now, at this exact point in time. Knowing the status of objects in the universe in the "here and now" only works well for our solar system — for Earth, the Sun, and our family of planets, asteroids, and comets.

As we look progressively out even into our Milky Way Galaxy, we begin to see things as they were, more so as distances increase. This makes interpretation difficult. How do we use what we see well into the universe's history to predict how the cosmos will end? It is a stupefyingly difficult problem.

Over the decades, astronomers have considered three leading possible outcomes for the distant future. The first says the universe has enough mass to eventually halt its expansion and will fall back on itself in a "Big Crunch." The second is a terrifying one, too: Some cosmological scenarios suggest that gravity will become too weak to hold individual galaxies together, and the universe will experience a "Big Rip" in which matter will be torn asunder.

The likeliest scenario, however, is the third, the "Big Freeze."

Most cosmologists believe the universe will expand forever and that a colder, darker cosmos lies in the distant future. As billions and even trillions of years roll on, redshifts will stretch photons into undetectable wavelengths, and eventually the supply of gas that could make new stars will be exhausted. Ultimately, stellar remnants also will be gone, leaving behind only black holes, which themselves will ultimately disappear due to Hawking radiation. An incredibly long way down the line, the universe will reach a point of inactivity called heat death.

The mileposts along the way through a Big Freeze scenario give us a particularly fascinating glimpse of the probable future. The current Stelliferous Era, when normal stars and galaxies are operating as they should be, has a long time to go. As we've seen, some 4 billion years from now, the Milky Way and Andromeda galaxies will merge into a single galaxy we call Milkomeda. Some 100 billion to 1 trillion years from now, the Local Group will merge into a giant galaxy.

The cosmos may have started with a bang but will most likely end with a whimper. Trillions of years from now, the universe likely will undergo heat death, becoming not only dark and dead, but also eternally cold. In this state, no thermodynamically free energy would be available, so no more processes could occur that would consume energy. It would be the ultimate end for any activity in the universe. What an anticlimax!

Yours truly,

David J. Eicher
Editor

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QG QUANTUM GRAVITY

EVERYTHING YOU NEED TO KNOW ABOUT THE UNIVERSE THIS MONTH . . .

HOT BYTES>>

TRENDING TO THE TOP

COSMIC SEEDS
Once life takes hold, it may spread between star systems via cosmic seeds in a well-defined pattern like an epidemic, say Harvard astronomers.

10 TATOOINES
Astronomers have now counted 10 planets known to orbit binary stars, similar to Luke Skywalker's home planet in *Star Wars*.

LIFE FROM COMETS
Impacts don't only cause extinctions. Experiments show early Earth-comet collisions could've made peptides, amino acid chains that are a key for life.

NASA/JPL-CALTECH/SETI INSTITUTE (EUROPA); NASA/JPL-CALTECH/R. HURT (COSMIC SEEDS, 10 TATOOINES); LLNL (LIFE FROM COMETS)

Jupiter's large moon Europa shows a cracked icy surface in this Galileo spacecraft image; an extensive subsurface ocean likely exists below the ice, which could host microbial life.

SNAPSHOT

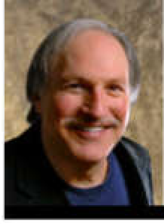
Could life exist on Europa?

A few places in our solar system could host microbes, and Jupiter's moon Europa is a prime candidate.

Planetary scientists believe Europa has an extensive liquid water ocean beneath its icy crust. The sixth-largest moon in the solar system, Europa is rich in silicates, probably has an iron core, and possesses a tenuous atmosphere and an icy surface striated by cracks and faults.

The extensive amounts of water ice on Europa and tidal flexing help to create the subsurface ocean, the existence of which was bolstered in 2014 with the detection of plate tectonics on the moon's thick ice crust, the first detection of this activity on a planetary body other than Earth.

Further, in 2013, NASA scientists detected phyllosilicate clay minerals on Europa's surface — and these minerals on Earth are often associated with organic molecules. The moon also displays evidence of water vapor plumes similar to those of Saturn's moon Enceladus. — **David J. Eicher**



STRANGE**UNIVERSE**

BY BOB BERMAN

Toys and compromises

Why all astronomy enthusiasts will happily equipment-shop forever.

The holiday season is here, and for us astro geeks that means toys.

In the quarter century I've written these columns in *Astronomy* and previously *Discover*, I've never mentioned the equipment I use. Since I love naked-eye astronomy so much, maybe I give the impression I'm not into optics. So now for the first time let me mention what I have, what I recommend, and how this whole business is a bit complex.

It's true, naked-eye astronomy is awesome. Away from city lights, what's more inspiring than the autumn Milky Way splitting the sky? When you think about it, the four greatest spectacles are all wonderful to the naked eye: total solar eclipses, major auroral displays, great comets, and brilliant meteor fireballs and bolides. None requires any equipment.

But I'm a big fan of binoculars. Of the displays just cited, total eclipses and comets are usually enhanced through them. So are the Milky Way and open clusters like the Pleiades (M45). During the 12 years I ran the astronomy program for the National Park Service at Yellowstone, the rangers and I tried countless visitors' pairs, and we particularly adored the Bausch & Lomb Audubons.

But then came image stabilization. That changed the ball game. I love my Canon 10x30 IS binoculars because they're lightweight and have amazing optics. My Canon 15x45 IS model is also cool, but almost twice as heavy. I also have 20x80s on a counterweighted swing arm binocular tripod. I use them all. Still, no stabilized model offers exit pupils above 4.2 millimeters, and in optimally dark conditions, if you're young enough so your eyes can adequately dilate, the brightness of a 5mm to 7mm exit pupil (as in a 7x50) makes it an attractive choice.

I also have solar binoculars on a portable Gemini mirror platform. This optically perfect, flat, swiveling-mirror arrangement lets the "glasses" point downward so that Sun viewing never requires craning necks upward. Toys.

WHEN IT COMES TO TELESCOPES, WE ENTER A WORLD OF COMPROMISE.

When it comes to telescopes, we enter a world of compromise. There is no perfect telescope design; each has its limitations. I own an old Celestron C5. Despite its setbacks, how else can I get a large motor-driven aperture in a portable configuration?

I've lived in a dark rural area for 44 years, and in 1982 I built a 16-by-20-foot observatory with a motorized roll-off roof. Its pier-mounted 12.5-inch f/6 Newtonian telescope has flawless optics, with a 5-inch Takahashi refractor riding piggyback. The massive mount handles the 250 pounds (110 kilograms) of instruments and counterweights, though the motor's clutch has a little backlash. Spectroscopes are part of every session.

I haven't done astrophotography since the old film days, but when I needed long-exposure tracking with no periodic error, my drive was excellent at delivering frustration. I'd labor 35 hours before decently capturing the Orion Nebula (M42). Hats off to all of you who take the gorgeous shots featured in this magazine.

Anyway, astro toys depend on what you like to observe, whether it involves photography, where you live, your budget, and your degree of patience. When price was no object, a wealthy friend bought a huge Keck-type dome and had a crane install a professionally mounted 24-inch PlaneWave, with a couple Takahashi refractors riding piggyback. The big scope's optical assembly cost $50,000 by itself. If only price were no obstacle for us all! And yet he overlooks a small city and has to endure a 4th-magnitude star limit.

If you have property in, say, Tibet, you could build a great observatory, but it would be hard to duck out for a decent sandwich. If you live in a city but can travel to a dark site, you could buy a big Dob or Schmidt, but you must be willing to drag the heavy thing around and periodically collimate the optics.

For those who want "easy," nothing's more hassle-free than a refractor, and these days even 4-inch models are affordable. But what will you do with it? We fanatics always find stuff. I once spent four hours staring at only Saturn when the night air was –13° F (–25° C), catching moments of astonishing detail unmatched by any photo. On the other hand, astrophotographers have their own sets of fussy requirements.

And if you get the 4-inch, the modest aperture precludes stunning looks at galaxies and globular clusters. The bottom line is that all telescopes involve trade-offs. So here is Santa's counsel: Make your decision, and then live with it serenely. Accept that no single instrument can do everything. Then that great holiday gift — or the goodie you've wanted for years — will give only pleasure.

Contact me about my strange universe by visiting **http://skymanbob.com.**

FROM OUR INBOX

Do *you* question?

Editor David Eicher's opinion piece on p. 9 of the September issue, "Part-time believers not needed," will come back to haunt him, if he lives long enough. He disses those who question what is now in the realm of science fiction. Let's remember *Star Trek* "replicators," "cloaking," "communicators," and "lasers." Or better yet, recall what the chairman of IBM reportedly stated in 1943, "There is a world market for maybe five computers." Or the Digital Equipment president who commented, "There is no reason anyone would want a computer in his home." Or even Lord Kelvin: "Heavier than air flying machines are impossible."
— Bob Found, Indian Harbour, Nova Scotia

We welcome your comments at Astronomy *Letters, P. O. Box 1612, Waukesha, WI 53187; or email to letters@astronomy.com. Please include your name, city, state, and country. Letters may be edited for space and clarity.*

BROWSE THE "STRANGE UNIVERSE" ARCHIVE AT **www.Astronomy.com/Berman.**

A SLOW DEATH. A section of the cosmos produces just half the energy it did 2 billion years ago, according to the multiwavelength Galaxy And Mass Assembly project, which surveyed 200,000 galaxies using many telescopes.

NASA STUDIES TRIP TO AN ICE GIANT

NEXT VOYAGER. In 1989, the Voyager 2 spacecraft became the first and last to see Neptune. NASA

NASA made its one and only visit to Neptune more than a quarter-century ago. And for years, planetary scientists have bemoaned a predicted 50-year gap between that Voyager 2 flyby and any follow-up mission.

Jim Green, NASA's head of planetary sciences, took a step toward narrowing that gap in August at the Outer Planets Assessment Group meeting in Laurel, Maryland, by announcing that NASA will study a potential flagship mission to Uranus and/or Neptune. If approved, it would be the next big mission following Mars2020 and the Europa flyby. Past flagship missions include Cassini, Galileo, and Voyager.

Neptune's moon Triton is an enticing option for many of the same reasons that prompted the Europa mission.

Triton is nearly as big as Earth's Moon but has smoke-stack-like plumes from ice volcanoes that erupt nitrogen frost onto its surface. For its part, Uranus has five moons big enough to be considered dwarf planets if they orbited the Sun on their own.

Argo, the last proposed mission to Neptune, was grounded because NASA didn't have enough plutonium to power all of its spacecraft, according to one of its designers. Candice Hansen of the Jet Propulsion Laboratory says there was a launch window from 2015 to 2020 that would put Argo at Neptune in a decade via gravity assists from Jupiter and Saturn. That timeline is now impossible to meet.

But she says the Space Launch System rocket that NASA is currently building could eliminate the need for gravity assists and allow a mission to get to Uranus or Neptune much faster.

Another exciting potential mission option announced in August is the Enceladus Life Finder, or ELF, which would orbit Saturn and sample the moon's curtain-like plumes of water that the Cassini mission found streaming from its icy surface. If approved, ELF would catch the water and then directly sample it for signs of life. — **Eric Betz**

HOW MANY YEARS IN SPACE?

FAST FACT Of the roughly 46,600 total person days spent in orbit, Russians have logged more than 25,000 compared to just over 17,700 for Americans.

SPACE STAMINA. Astronaut Scott Kelly is making headlines with his "Year in Space." And when he returns in March, Kelly will hold the record for the American with the most off-Earth time at 522 days. But that doesn't even crack the top 10 list of Russians in space. In July, cosmonaut Gennady Padalka, orbiting alongside Kelly, broke his comrade Sergei Krikalev's record of 803 days in orbit. *ASTRONOMY*: ERIC BETZ AND LUANN BELTER; NASA/BILL INGALLS (KELLY IMAGE)

BRIEFCASE

DOUBLE BLACK HOLE

Astronomers found that Markarian 231, the closest galaxy to Earth that hosts a quasar — an actively feeding black hole — actually sports twins. Research published August 20 in *The Astrophysical Journal* shows that a smaller black hole circles the supermassive central one, carving out a doughnut hole around the galaxy's core. Since most galaxies contain central black holes and galaxy mergers are common, astronomers suspect that binary black holes may be as well. Like their hosts, the black holes should eventually merge.

LADEE FINDS NEON

NASA's Lunar Atmosphere and Dust Environment Explorer (LADEE) spacecraft confirmed the presence of neon on the Moon, which has been suspected since the Apollo days, but only proven in a study published May 28 in *Geophysical Research Letters*. The Moon's atmosphere is extremely thin — 100 trillion times less dense than the air we breathe on Earth. Most of it is thought to come from the solar wind, but LADEE also revealed that lunar rocks outgas argon and helium.

ETERNAL RING

A new study published in the August 4 issue of the *Proceedings of the National Academy of Sciences* answers a long-standing question about the size of particles in Saturn's rings. Researchers proved that the distribution of dust and pebbles is exactly what should occur in a system where collisions are common, so that small grains stick together and larger ones break apart at steady rates. — **Korey Haynes**

WHERE IN THE BELT? Scientists used Earth-based observatories to study a passing asteroid and then compared it to meteorites that have plummeted to Earth in the past. NASA/ESA/STScI

Mundane meteorites have unexpected origin

Astronomers have traditionally associated the most common type of meteorites, known as H chondrites, with a main-belt asteroid called 6 Hebe. This asteroid orbits roughly three times for every trip Jupiter takes around the Sun, placing it in a resonance orbit, which makes it a likely suspect to send accompanying rocky missiles toward Earth.

However, spectral observations of a passing asteroid called 2007 PA_8, published in the July 20 issue of *The Astrophysical Journal*, reveal its remarkable similarities to H chondrites, implying that some of these meteorites might have originated with 2007 PA_8's family farther out in the main belt. — **K. H.**

ASTRO**NEWS** **EIGHT NEW DWARFS.** The Dark Energy Survey, which enlists one of the world's most powerful digital cameras, turned up eight new faint dwarf satellite galaxies circling the Milky Way, bringing the team's total to 17 for the year.

TMT case advances to Hawaii's Supreme Court

The international astronomy collaboration seeking to build the Thirty Meter Telescope (TMT) on Hawaii's Mauna Kea has seen progress grind to a halt as protesters block construction physically on the mountain access road and legally in courts. The police have undertaken multiple rounds of arrests and Hawaii's governor, after initially calling for a construction halt, later confirmed the telescope's right to proceed, though he advocated concessions that include removing a quarter of the telescopes already present. The site is currently home to 13 observatories.

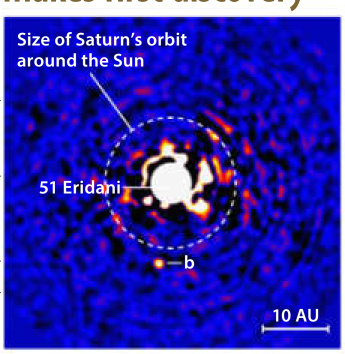
Protesters lost their initial court case and first appeal, with the courts ruling that the Board of Land and Natural Resources (BLNR) had fulfilled its duties in evaluating TMT's environmental impact and approving construction. But the Supreme Court of Hawaii accepted protesters' second appeal, hearing oral arguments August 27. As of press time, the court had yet to issue a ruling, but during the hearing the justices rebuked the BLNR for approving construction before they held a contested (public) hearing, citing due process and likening their actions to a judge passing sentence before hearing a case. Justices also questioned the board's reasoning that the "incremental" damage projected by TMT's environmental impact statement was enough to exonerate it from the same document's finding that "past construction of these observatories has had cumulative impacts … that are substantial, significant, and adverse."

PROTECTION VIA PROTEST. The Mauna Kea controversy's complexities are made clear in this image of police joining hands in prayer with protesters before carrying out a round of arrests this spring. EVAN BORDESSA

No court has issued a stay, so construction may legally proceed until and unless the Supreme Court overturns the initial case, though protests have halted construction effectively thus far.

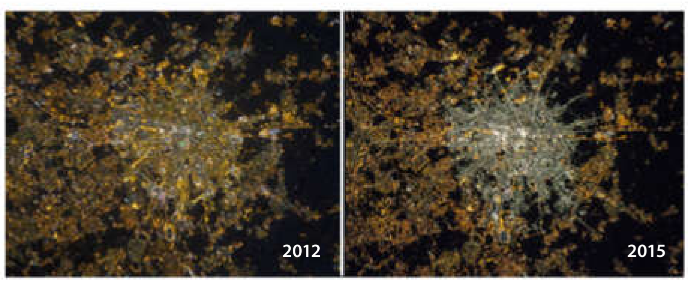
Native Hawaiians are driving the protests as they seek to protect a vital and active cultural heritage site, while TMT advocates point out Mauna Kea's exceptional and unique qualities as an observing site. — **K. H.**

Gemini Planet Imager makes first discovery



J. RAMEAU (UDEM) AND C. MAROIS (NRC HERZBERG)

DIRECT DETECTION. Astronomers have discovered thousands of exoplanets through indirect methods, i.e., observing a planet's effects on the characteristics of its parent star, but they have only directly imaged a handful of worlds. Scientists using the new Gemini Observatory Planet Imager (GPI) hope to change that because direct detection allows measurements of an exoplanet's atmospheric composition and luminosity. In the August 13 *Science* Express, they announced their first GPI find: 51 Eridani b, an exoplanet 100 light-years away with twice Jupiter's mass orbiting its young star at a distance a little farther than Saturn is from the Sun. The exoplanet shows the strongest methane signature ever detected on a world beyond our solar system and has a temperature around 800° F (430° C). Such characteristics point to a planet that resembles an infant Jupiter. — **Karri Ferron**



NIGHT LIGHTS. The Cities at Night project is using astronaut photos like these captured from the International Space Station to study global light pollution. Here Milan, Italy, appears noticeably brighter after the city's conversion to LED streetlights. NASA/ESA

Light pollution gets new measure

For years, astronomers and night-sky advocates have warned about the potential impact of new LED streetlights, which are being rapidly installed around the world in place of the older, yellower high-pressure sodium vapor lights. LEDs, unlike their predecessors, spread their light across the electromagnetic spectrum instead of confining their light pollution to one small band. Los Angeles has already added 165,000 LED streetlights. New York City says it will convert some 250,000. Smaller cities also are following suit.

Ecologists have discovered added negative consequences for wildlife associated with LEDs. The American Medical Association has warned about health impacts for humans. And astronomers say their light is harder to filter.

But the first real measure of increased LED light pollution came in August at the International Astronomical Union meeting in Hawaii. A group called Cities at Night is using astronaut photos of Earth to create a Google Earth-style map of our world after dark. The photos show how cities like Los Angeles grow brighter after LED conversion projects.

Cities at Night researchers now are enlisting the public's help as they build up a database using hundreds of photos from the International Space Station. — **E. B.**

QUICK TAKES

GRAVITATIONAL CONSTANT
Gravity's influence is constant throughout the universe, according to a decades-long study of a distant pulsar — the rapidly spinning remains of a massive star turned supernova.

•

NEUTRINOS CONFIRMED
Antarctica's IceCube Neutrino Observatory refined its 2013 breakthrough Southern Hemisphere measurement of neutrinos from outside our galaxy by pointing the instrument through Earth and confirming the elusive particles from the Northern Hemisphere too.

•

CORONAL HEATING
Astronomers solved the 70-year mystery of how the Sun's corona, or outer layer, reaches a million degrees Celsius by catching magnetic waves as they resonate and one strengthens, causing turbulence.

•

FULL HOUSE
International Space Station crew members from Russia, Kazakhstan, and Denmark launched in a Soyuz capsule September 2, boosting the orbiting research lab's staff to nine for the first time since 2013.

•

TEAM EUROPA
The scientists who will lead NASA's Europa exploration mission a decade from now met for the first time August 10 at the Jet Propulsion Laboratory in Pasadena, California. The all-star team includes veterans of New Horizons, Cassini, Galileo, and Voyager.

•

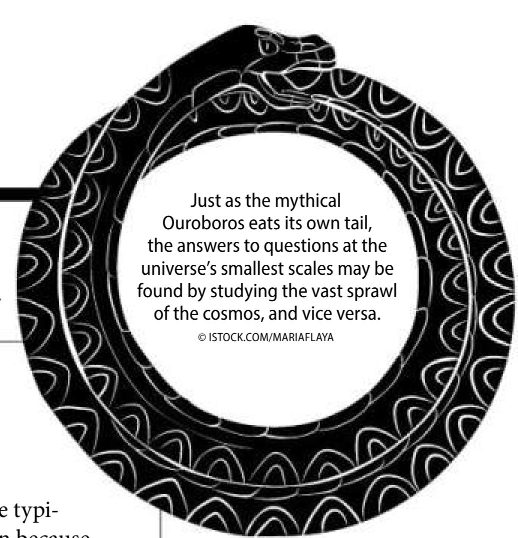
SUPERNOVA SPIN
Shock waves from a nearby supernova could have not only injected radioactive isotopes, but also set our solar system spinning when it was still a cloud, according to new computer models.

•

ENGINE TEST
In August, NASA completed the first development testing on the R-25 rocket engines that will one day power its Space Launch System — **E. B.**

FOR**YOUR**CONSIDERATION
BY JEFF HESTER

Big meets small
The Ouroboros of today's physics.



Just as the mythical Ouroboros eats its own tail, the answers to questions at the universe's smallest scales may be found by studying the vast sprawl of the cosmos, and vice versa.
© ISTOCK.COM/MARIAFLAYA

"Space is big. Really big. You just won't believe how vastly, hugely, mind-bogglingly big it is. I mean, you may think it's a long way down the road to the chemist, but that's just peanuts to space." (Douglas Adams, *The Hitchhiker's Guide to the Galaxy*)

This issue of *Astronomy* follows the journey taken in the 1977 short film *Powers of Ten* outward into the cosmos. Twenty-six powers of 10 separate the scale of the observable universe from the scale of the room that likely surrounds you as you read these words. Yet the trip outward is only part of the story. Instead of adding zeros to the left of the decimal point, we can add zeros to its right, taking us into an ever more microscopic realm. Each journey is as extraordinary as the other.

Ten steps outward from the center of the Sun, and we reach the size of our local star and its extended corona. Something like a hundred billion trillion (10^{23}) stars inhabit the observable universe. Ten steps inward, and we reach the scale of atoms. To find a hundred billion trillion atoms, look no further than your thumb!

Expanding our cosmic scope by four additional powers of 10 swallows the Kuiper Belt and many of the hundreds of billions of comets that surround the solar system. Stepping in by four more levels brings us to atomic nuclei, with densities a hundred billion times that of water.

Twenty-four powers of 10 out, we find superclusters of galaxies. Twenty-four powers of 10 inward, we find the scale of the elusive neutrino. After 26 powers of 10, we have come to the end of the line in one direction, the scale of the observable universe. But in the other direction, there is still a long way to go. We have to shrink our gaze through 35 powers of 10 to finally arrive at the Planck length. This is the domain of string theory and may represent reality's ultimate granularity.

The 61 powers of 10 spanned by today's physics goes well beyond those discussed in 1977. One of the most profound discoveries of the last 40 years is that as we push to extremes in each direction, the snake eats its own tail!

Fundamental advances in science typically do not happen because of a theory's continued success. Breakthroughs come when the predictions of an important theory start to fail. Maxwell's theory of electromagnetic radiation predicted that objects of even modest temperature should glow intensely with ultraviolet light. Sorting that out along with another "oops!" or three pointed the way to quantum mechanics.

After 200 years, the success of Newton's physics had led some to declare that nothing remained of science but mopping up a few loose ends. All that gave way to relativity because a simple experiment failed to find expected variations in the speed of light.

The failed predictions of a powerful, successful theory are nature's way of telling us where there are new things to learn. So it can be really frustrating when a theory stubbornly persists in making correct predictions. Such is the case with the standard model of particle physics. For four decades physicists have pushed on their particle accelerators, trying to break through to physics beyond the standard model, and for four decades they have failed.

Yet there *are* cracks in the edifice of the standard model. Those cracks were revealed not by particle accelerators, but by observations of the cosmos.

The first hole in the dike actually predates the standard model itself. In the 1960s, scientists measuring neutrinos from the Sun found only a third of the expected number. We now know that all of the expected neutrinos are there; they just slosh around among three different forms. The standard model says that can't happen!

Cosmology presents even deeper challenges. The standard model is a resounding success but for the niggling fact that between dark matter and dark energy, the standard model accounts for less than 5 percent of the stuff of which the universe is made. And when particle physicists use quantum field theory to try to explain dark energy, they get the wrong answer by 120 powers of 10. That has to go down as the worst prediction in history! Finally, it is Big Bang cosmology that breaks our understanding of gravity by squeezing it into too small a quantum box.

Powers of Ten was made to highlight the vast range of physical scales in the universe. But as the frontiers of cosmology and the frontiers of particle physics merged, our perspective on scale has changed. Viewed from one direction, the structure and fate of the universe hinge on as yet poorly understood particle physics beyond the standard model. Viewed from the other direction, the Big Bang is the ultimate high-energy accelerator, and the cosmos itself is the debris that we have to study from that most extreme of all particle experiments.

Jeff Hester is a keynote speaker, coach, and astrophysicist. Follow his thoughts at **jeff-hester.com.**

FROM OUR INBOX

Science or science fiction?

Bob Berman's article "Multiverses: Science or science fiction?" (p. 28) in the September issue was exceptional. Instead of defending the multiverse theory or debunking it out of hand, he provided a cogent, balanced argument. The "theory of anything" approach promoted by adherents of the multiverse, by purporting to champion the multiverse idea, dilutes its impact by its very nature — anything that can happen mathematically does happen. And, without any substantive possibility of experimentally verifying the theory or applying the falsification principle, it must remain problematic at best. I especially appreciated the methodical approach that Berman brings to his analysis. We need more scientists dedicated to finding the truth, wherever it may lie. — **Steven Cotton,** Cottonwood, California

BROWSE THE "FOR YOUR CONSIDERATION" ARCHIVE AT **www.Astronomy.com/Hester.**

ASTRO**NEWS** **STATION SUCCESS.** A Japanese cargo ship reached the International Space Station on August 24 with supplies and a new electron telescope.

Ceres' lonely mountain puzzles Dawn team

PUZZLING PYRAMID. Ceres' asteroid belt home means it's hit regularly by debris. However, astronomers don't think an impact can explain this mountain.

The inner solar system's only dwarf planet took astronomers by surprise when NASA's Dawn spacecraft arrived early this year. Many expected that impact craters on Texas-sized Ceres would "relax" due to abundant ice thought to lie just beneath its surface. Instead, they found a heavily cratered world with few outer signs of the hidden inner ice reservoir.

But that's not the weirdest part. Ceres has an enormous mountain — just one. At some 21,000 feet (6,400 meters) in elevation, the pyramid-shaped peak towers higher than Alaska's Denali, America's highest mountain.

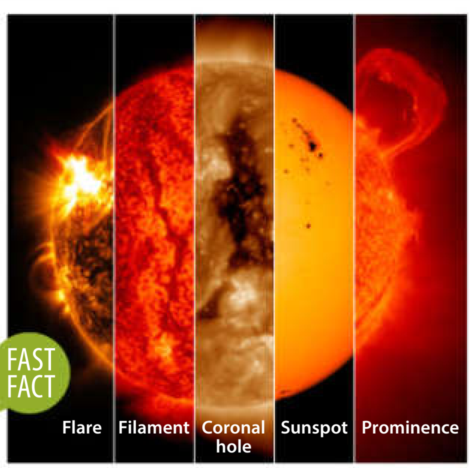
"The team is totally baffled by the mountain at the present time," Dawn Principal Investigator Chris Russell says. "We don't really see how the mountain got made."

Some early theories suggested a foreign object impact, but the mountain looks like it's made from the same stuff as Ceres. Scientists are also looking at volcanoes around the solar system in search of similarities but have so far come up mostly empty-handed. The mountain does bear resemblance to some others — those seen on Pluto.

"The heights of [Pluto's] mountains, and the shape of the mountains, look very similar to the shape of our mountains," Russell says. "There is a story there, but we haven't figured out what the answer is." — **E. B.**

PEAKABOO. Ceres has but one mountain. Mysteriously, it vaults 4 miles (6 kilometers) above the dwarf planet's plains. NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

WHAT'S THAT THING ON THE SUN?



SOLAR FLAIR. The Sun's outer layers sport a variety of transient features to delight observers, all tied to the Sun's tangled, twisted magnetic field. These phenomena appear at slightly different layers or stand out best at different wavelengths, hence the variety of images combined here. *ASTRONOMY*: LUANN BELTER/KOREY HAYNES, AFTER NASA/SDO (FILAMENT, CORONAL HOLE, FLARE, SUNSPOT); ESA/NASA/SOHO (PROMINENCE)

FAST FACT

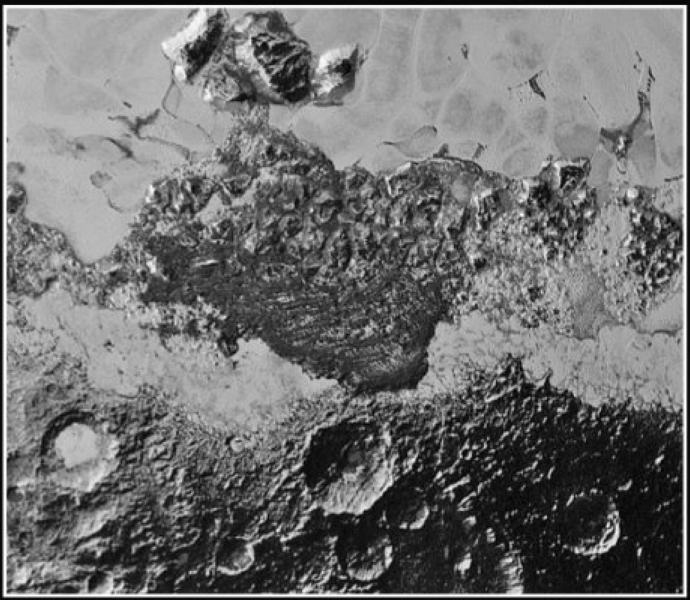
Sunspots usually occur in pairs or clusters of opposite magnetic polarity.

A COMPLICATED PICTURE OF PLUTO

After six weeks of relative quiet from New Horizons scientists as they recovered from the probe's historic flyby of the Pluto system July 14, they got back to work over Labor Day weekend. The first images returned from a scheduled yearlong downlink of data continue to show a more complex world than anyone ever imagined. "Pluto is showing us a diversity of landforms and complexity of processes that rival anything we've seen in the solar system," says Principal Investigator Alan Stern of the Southwest Research Institute in Boulder, Colorado. "If an artist had painted this Pluto before our flyby, I probably would have called it over the top — but that's what's actually there."

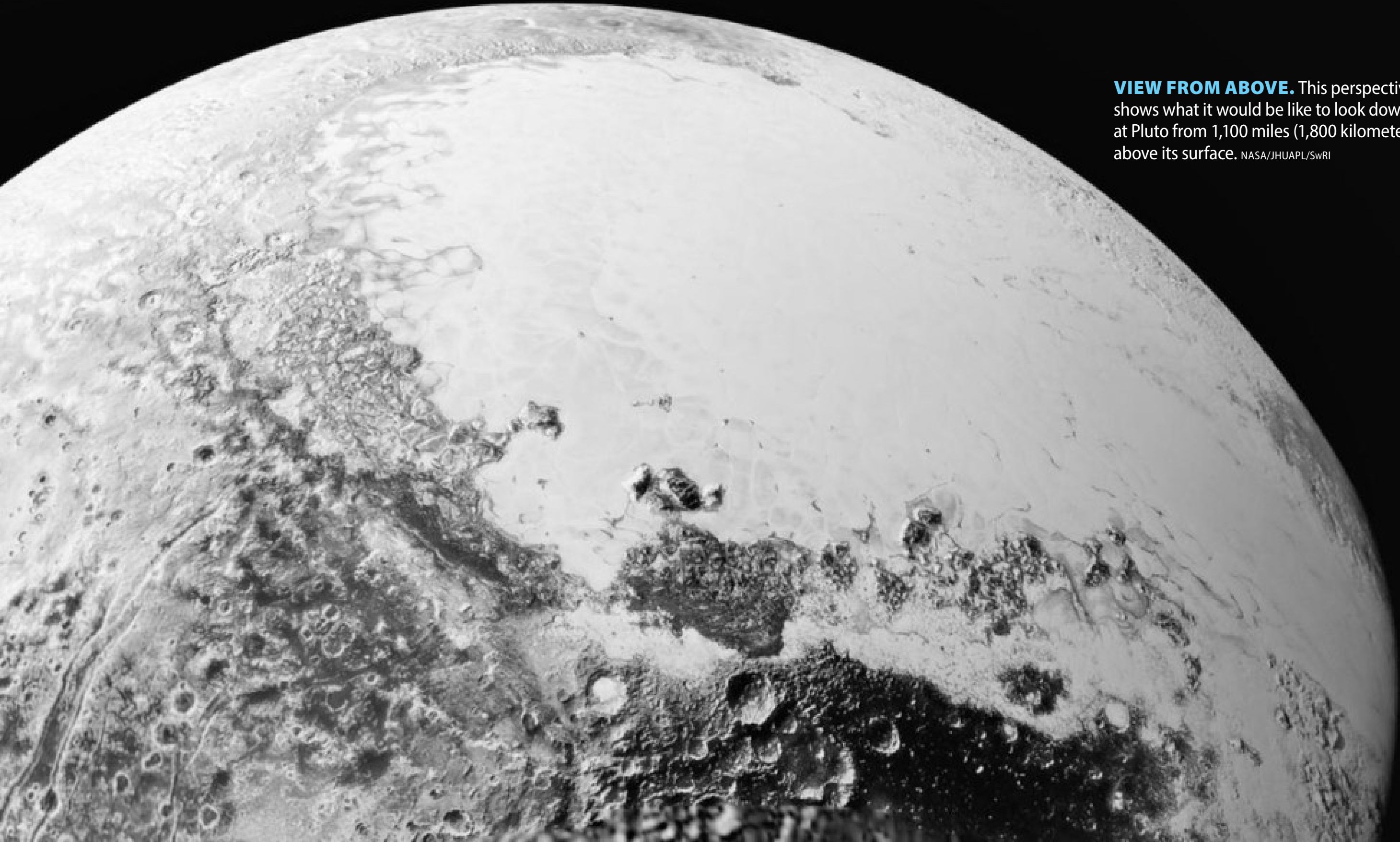
Among the most intriguing features revealed are some smooth, dark regions that could be wind-blown dunes. "Seeing dunes on Pluto — if that is what they are — would be completely wild because Pluto's atmosphere is so thin," says New Horizons team member William B. McKinnon of Washington University in St. Louis. "Either Pluto had a thicker atmosphere in the past, or some process we haven't figured out is at work. It's a head-scratcher."

And even as New Horizons continues to send back stored data from the flyby, the spacecraft is already preparing for the next phase of its mission — assuming it gets NASA approval. The probe was designed to go beyond Pluto to explore at least one other icy body in the Kuiper Belt, but at the time of launch in 2006, any future targets were a mystery. In 2014, the Hubble Space Telescope uncovered five potential Kuiper Belt objects (KBOs) for New Horizons to explore, and on August 28, NASA selected one, designated 2014 MU_{69}, based on the mission team's recommendation. The 30-mile-wide (45 kilometers) KBO lies nearly a billion miles beyond Pluto and likely formed where it now orbits.



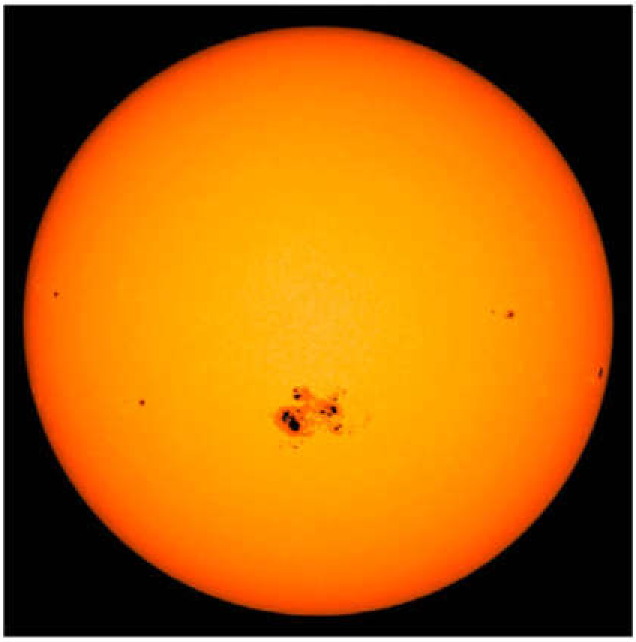
OLD AND NEW. This 220-mile-wide (350 kilometers) view of Pluto's surface shows many intriguing features, including dark ridges that resemble dunes (upper left and right) and ancient, heavily cratered terrain jutting up against smooth and therefore relatively young areas. NASA/JHUAPL/SwRI

Selecting New Horizons' next target right after the Pluto flyby was necessary in order for the spacecraft to start making maneuvers before the end of the year to put it on the right trajectory without wasting fuel. Still, mission scientists need further approval to conduct actual science during a flyby. In the coming year, they will submit a proposal to NASA requesting funding for this extended mission as part of the space agency's planetary science portfolio. If after an independent review NASA provides the go-ahead, New Horizons will explore 2014 MU_{69} on January 1, 2019. **— K. F.**



VIEW FROM ABOVE. This perspective shows what it would be like to look down at Pluto from 1,100 miles (1,800 kilometers) above its surface. NASA/JHUAPL/SwRI

ASTRO**NEWS**



COUNTING SUNSPOTS. NASA's Solar Dynamics Observatory caught this nearly 80,000-mile-wide (130,000 kilometers) sunspot in 2014 during a high point of the recent solar cycle. NASA/SDO

Sunspots can't explain ongoing climate change

Changes in our Sun's activity levels can't explain Earth's current climate change, according to a corrected history of sunspots announced at the International Astronomical Union meeting in Hawaii on August 7.

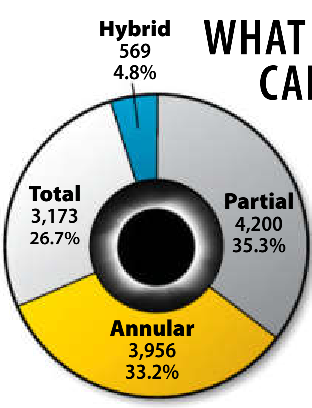
The Sunspot Number is the longest ongoing science experiment in the world and is used as a crucial tool for understanding our Sun's activity, as well as Earth's climate. Its history includes the Maunder minimum, a period between 1645 and 1715 where the Sun had a strong drop in sunspot activity that coincided with harsh winters.

But in the years since that low, scientists have generally agreed that sunspots have increased, even though some disagreed about what that implied.

However, astronomers have now released Sunspot Number Version 2.0, which found a significantly different sunspot count between 1885 and 1945. The international team of astronomers said the previous count contained a major calibration error that misled some theorists.

The group says climate evolution models now need to be recalibrated using the updated information. — **E. B.**

WHAT TYPE OF ECLIPSE CAN WE EXPECT?



SOLAR SURVEY. In the 5,000 years from 2,000 B.C. to A.D. 3,000, an astounding 11,898 solar eclipses will occur. This chart shows how many of each type Earth will experience. ASTRONOMY: MICHAEL E. BAKICH/ROEN KELLY; MIKE REYNOLDS (ECLIPSE)

FAST FACT

A hybrid eclipse is annular along some of its path and total along the rest.

25 years ago in *Astronomy*

Astronomy's December 1990 issue outlined the NASA/European Space Agency (ESA) joint Cassini-Huygens mission, as well as the Comet Rendezvous Asteroid Flyby (CRAF). Cassini's successful four-year mission has lasted 11 years and will end in 2017. CRAF fell victim to congressional funding priorities, but subsequent spacecraft, including ESA's Rosetta mission, eventually accomplished its goals.

10 years ago in *Astronomy*

For the December 2005 issue, Senior Editor Richard Talcott teamed up with master space artist Adolf Schaller to produce an illustrated spread titled "A comet's tale." The two-page infographic outlined astronomers' best understandings of comets and their impacts on earthly life, including the possibility of supplying the ingredients for RNA and DNA — a role ESA's Rosetta mission confirmed in July. — **E. B.**

21

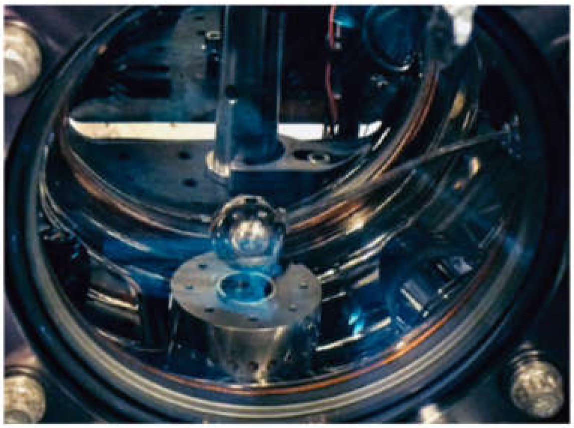
The number of ultra high-energy detections by the IceCube observatory, confirming the existence of neutrinos from our galaxy and beyond.

ASTRONEWS **3 FEET DEEP.** Decades of data from NASA spacecraft show Earth is locked into at least 3 feet (1 meter) of sea level rise, the agency said August 25. It's less certain if that will happen within a century or take longer.

Dark energy hides like a chameleon

Physicists believe that the majority of the universe is composed of dark energy, which they infer from observations but have so far been unable to measure directly. One reason for this could be that dark energy particles "hide" like a chameleon, changing their mass depending on the density of material around them. Thus in the empty depths of space, the particles would have strong fields, able to push the cosmos apart, as modern theory requires. But in a lab setting, they would be weak and almost impossible to detect.

In a study appearing in the August 21 issue of *Science*, physicists searched for these elusive particles by creating an extremely low-density environment and watching how individual atoms behaved closer and farther from a dense ball. They saw no differences, but their work was still able to rule out a huge range of possibilities for dark energy and limit the chameleon fields to a million times weaker than those of gravity. **— K. H.**

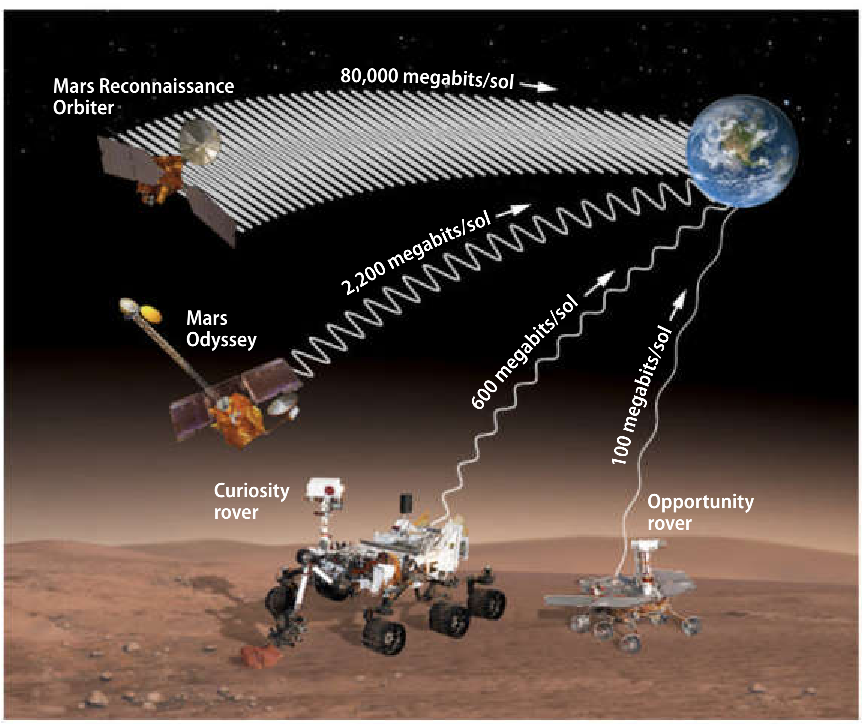


SCIENCE IN A SPHERE. Researchers looked for evidence of dark energy chameleon fields inside this vacuum chamber, a hollow space with a trillionth the pressure of the air outside, which allowed them to search for the sneaky signals. HOLGER MÜLLER

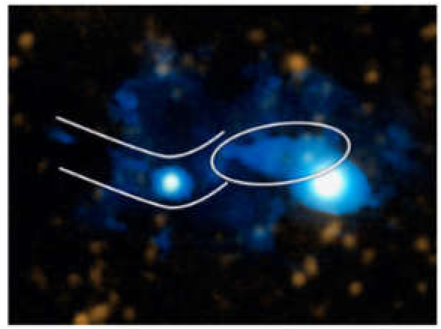
BEAMING DATA BACK HOME

The two orbiters relay most of Curiosity's and Opportunity's data. MRO's total includes about 500 megabits/sol and Odyssey's some 200 megabits/sol from the rovers.

FAST FACT



MARTIAN ARMADA. NASA currently has five spacecraft studying Mars close-up. But when it comes to the amount of information returned to Earth, the Mars Reconnaissance Orbiter (MRO) stands above all others. On average, it returns about 80,000 megabits of data each martian day, or sol (one sol equals 1.03 Earth days). This graphic compares MRO with the other three probes currently on extended missions. Because data rates vary with Mars' distance from Earth — in the same way a wireless connection slows down with distance — it does not include the recently arrived MAVEN orbiter. *ASTRONOMY*: RICHARD TALCOTT, ROEN KELLY AND KELLIE JAEGER



MODEL PROTOGALAXY. Using the Cosmic Web Imager, astronomers have discovered a distant protogalaxy (circled) being fueled by a filament of cold gas from the cosmic web (outlined). This is the first observational proof for the cold-flow model of galaxy formation. C. MARTIN/PCWI/CALTECH

A distant clue to galaxy formation

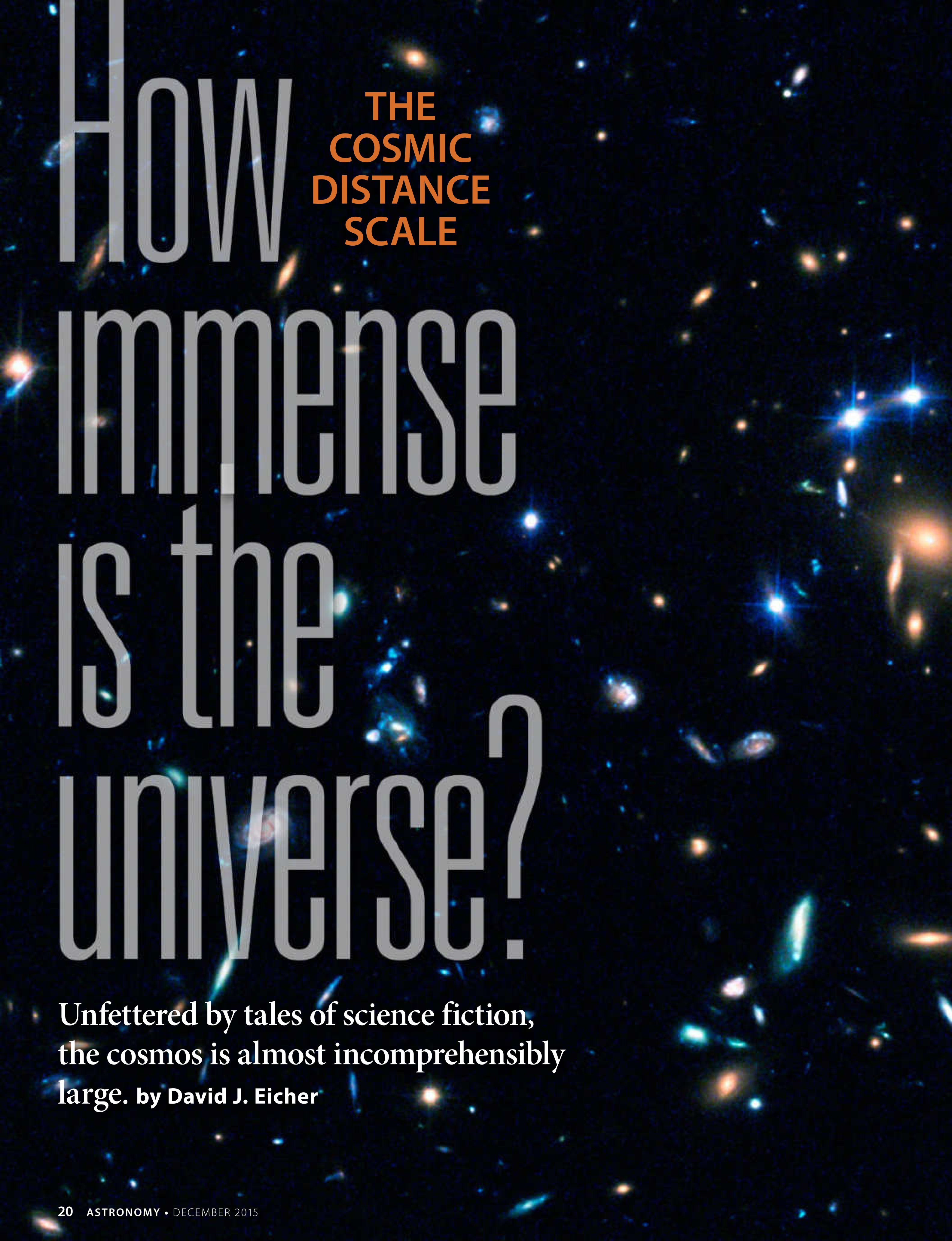
By peering deep into the cosmos to a time when the universe was less than 4 billion years old, scientists have uncovered key evidence to help support a model of galaxy formation that's been hotly debated for over a decade. Astronomers led by Christopher Martin of the California Institute of Technology in Pasadena have uncovered a swirling disk 400,000 light-years across — what's called a protogalaxy — that is actively being fed by a filament connected to the cosmic web of gas that extends throughout the universe. "This is the first smoking-gun evidence for how galaxies form," Martin says.

The discovery provides strong observational support for the cold-flow model of galaxy formation. This model posits that relatively cold gas in the early cosmos from the intergalactic medium that makes up the cosmic web is responsible for fueling rapid star formation and therefore galaxy development.

Its competing standard model of galaxy formation focuses on dark matter halo collapses as the trigger, but this theory does not fit with the fast star formation recently discovered in galaxies that existed just 2 billion years after the Big Bang. The cold-flow model can produce such rapid star birth and enough spin to form extended rotating disks, but observational evidence had been lacking until this protogalaxy discovery, which appeared in the August 13 issue of *Nature*. Further, Martin and his team already have found two additional swirling disks that could provide more support for the newer model. **— K. F.**

5,000

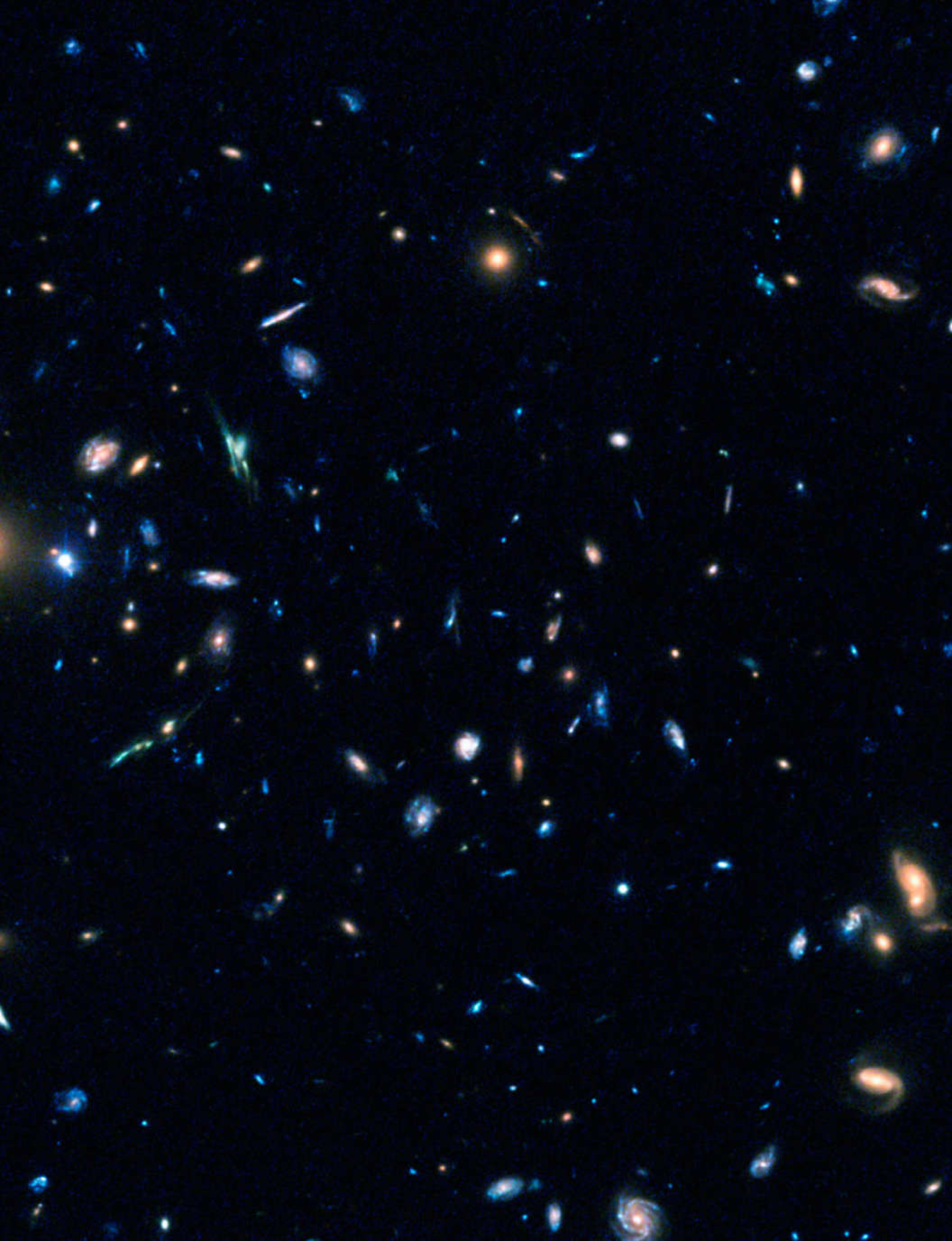
The solar masses contained in NGC 1313, a newly identified intermediate mass black hole. Astronomers say it's just the seventh of its kind now known.



THE COSMIC DISTANCE SCALE

How immense is the universe?

Unfettered by tales of science fiction, the cosmos is almost incomprehensibly large. by **David J. Eicher**



IT'S ABSOLUTELY AMAZING to know that shortly after the Big Bang, the universe was a relatively small, nearly infinitely dense place. It boggles the mind.

But that was 13.8 billion years ago. The expanding universe means the entirety of what we know is now incredibly large — and is getting more immense every day.

This is one area that two generations of science-fiction movies have seriously distorted in the minds of the public. The general feeling that technology is pretty good and will know almost no bounds, and that we can almost certainly one day travel between star systems, is pretty much taken on faith.

But what the sci-fi movies have failed to communicate, among other things, is that the universe is an *immensely large* place. Even distances between the nearest objects are staggering, and the distances across the Milky Way Galaxy and certainly between galaxies in the universe are astonishingly huge to living beings stuck on a planet. A model of the Milky Way wherein the Sun is a grain of sand brings this home. On this scale, stars — sand grains — are 4 miles (6 kilometers) apart in the Milky Way's disk and the disk is about 40,000 miles (60,000km) across. Now who wants to go traveling from grain to grain?

The concept of the size of the universe has taken a huge stride forward in just the last few years. There was a time not too long ago when astronomers did not know even the approximate size of the cosmos with any degree of accuracy. We still don't know with high precision.

M74: NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)-ESA/HUBBLE COLLABORATION

Incredible expansion

The Big Bang theory tells us that once the universe was very small. We know the fastest that radiation or any information can travel is the speed of light, 186,000 miles per second (300,000 km/s). We're confident that the universe is 13.8 billion years old. We also know that a light-year is equal to approximately 6 trillion miles (9.4 trillion km). In nearly 14 billion years, on first blush, we might expect radiation to expand radially outward to something like 30 billion light-years across.

David J. Eicher *is editor of* Astronomy *magazine. He has marveled at the cosmic distance scale since the mid-1970s.*

But remember that the Big Bang was not like an explosion that went off in a room. Following the Big Bang, space-time itself expanded radially outward at all points, meaning all of space expanded too, not just the stuff within it. (The term space-time refers to the mathematical model that combines space and time into a single, interwoven medium.)

As the expansion of the universe began, just 1 centimeter of "empty space" interstitially became 2 centimeters over time, and so on. So the best ideas about the size of the universe allowing for its expansion over time point to a radius of slightly more than 46 billion light-years and therefore a diameter for the universe of approximately 93 billion light-years.

But there's a major proviso to this result. That diameter refers to the visible universe we can see from Earth. Inflation theory, if correct — and it has widespread support among cosmologists — suggests the portion of the universe we can see is by no means the entire cosmos. Some cosmologists propose that the universe is infinite. But let's work with what we really have and say the cosmos, at least the part that we can observe, is about 93 billion light-years across.

A thorough understanding of our neighborhood, our solar system, our area of the Milky Way, our galaxy, and so on is

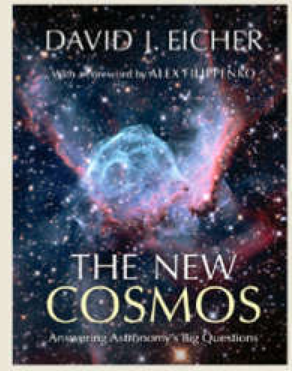
PREVIOUS PAGE: SDSS J1004+4112: ESA/NASA/K. SHARON (TEL AVIV UNIV.)/E. OFEK (CALTECH)

THE NEW COSMOS: ANSWERING ASTRONOMY'S BIG QUESTIONS

This story is an excerpt from David J. Eicher's new book, *The New Cosmos* (300 pp., hardcover, Cambridge University Press, New York, with 100,000 words of text and 100 color illustrations, foreword by Alex Filippenko, ISBN 978-1107068858). The book is available at bookstores and online retailers.

The New Cosmos seeks to fill a major gap in the story of astronomy, planetary science, and cosmology. Over the past decade, astronomers, planetary scientists, and cosmologists have answered — or are closing in on the answers to — some of the biggest questions about the universe. Eicher presents an exploration of the cosmos that provides a balanced and precise view of the latest discoveries.

Detailed and entertaining narratives on compelling topics such as how the Sun will die, the end of life on Earth, why Venus turned itself inside-out, the Big Bang theory, the mysteries of dark matter and dark energy, and the meaning of life in the universe are supported by numerous color illustrations including



photos, maps, and explanatory diagrams. In each chapter, the author sets out the scientific history of a specific question or problem before tracing the modern observations and evidence in order to solve it. This fall you can join Eicher on this fascinating journey through the cosmos.

critical to comprehending how the universe works. And exploring the cosmic distance scale also unveils a slew of interesting objects astronomers use to determine distances to objects near and far.

The seeds of measuring the universe stretch back in time all the way to the Greek astronomer Aristarchus of Samos (ca. 310–230 B.C.), who had correct notions of parallax in mind with regard to distances of the Sun and Moon. Parallax is the technique of measuring the offset of nearer bodies to the distant background of stars and geometrically calculating a distance.

Little progress took place after Aristarchus until Polish astronomer Nicolas Copernicus (1473–1543) proposed the heliocentric model of the cosmos, and it was one of the last great visual astronomers, Danish nobleman Tycho Brahe (1546–1601), who made the first parallax measurements of comets and helped define a more modern distance scale to nearby objects.

Starting close to home

Let's pause for a moment to appreciate the physical scale of just our solar system — only the Sun, its attendant planets and debris, and our little island of life inside it. To envision our immediate vicinity a little better in your mind, imagine a scale solar system with the Sun on one end and 1 centimeter representing the distance between our star and Earth, called an astronomical unit (AU). That is, 1 AU = 1 centimeter. You actually can draw this out on paper to help crystallize it in your mind. Tape several sheets of paper together and have at it. With the Sun at one end, Earth is 1 centimeter away, and Mercury and Venus are in there too at 0.4 centimeter and 0.7 centimeter, respectively. Outward from Earth, we have Mars at 1.5 centimeters, the main-belt asteroids centered around 2.5 centimeters, Jupiter at 5 centimeters, Saturn at 9.5 centimeters, Uranus at 19 centimeters, and Neptune at 30 centimeters. Pluto can be placed at 40 centimeters.

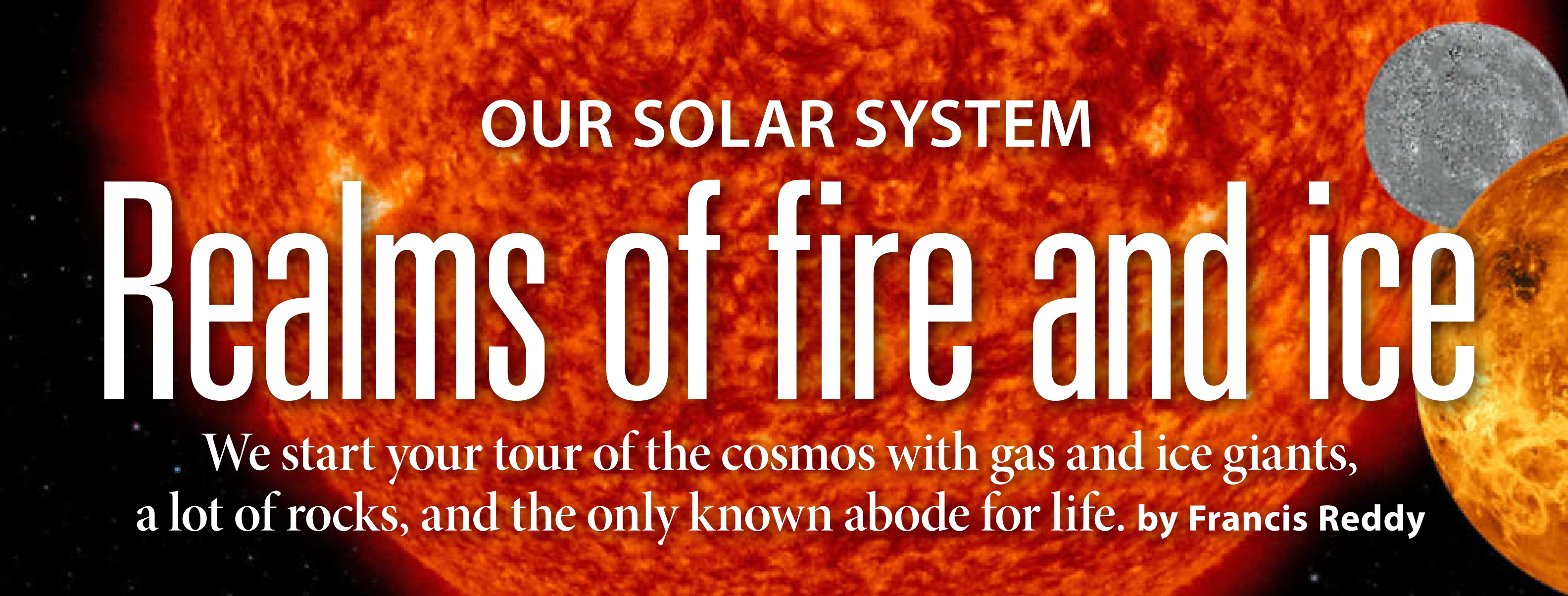
The outer solar system is sparse, consisting of the Kuiper Belt region from 30 to 50 centimeters from the Sun, and you can even indicate some of the more interesting objects in the area to keep Pluto company — Haumea at 40 centimeters, Makemake at 45 centimeters, and Eris at 60 centimeters. Now you can finish by indicating the region of the scattered disk, a sparse body of energetically "spun up" icy asteroids, between 50 and 100 centimeters from the Sun. This gives you a complete scale model of the solar system in a region spanning 1 meter, or 3 feet, across.

Now appreciate that on this scale, the inner edge of the Oort Cloud, the vast halo of 2 trillion comets on the solar system's perimeter, is 100 meters (109 yards, more than an American football field) farther away than the edge of your diagram. The outer edge of the Oort Cloud, on this scale, is 1,000 meters (0.6 mile, more than 10 football fields) away.

Yet as human astronaut-explorers, we only have traveled as far away as the Moon, about 1⁄389 AU, or on our scale 1⁄389 centimeter, from Earth, which on this scale is about the size of a human red blood cell. That distance is imperceptibly close to our planet's "dot" on our scale drawing.

And yet the distances to the nearest stars are larger than our imagined scale of the Oort Cloud. And then come perhaps 400 billion stars scattered across the bright disk of our Milky Way Galaxy, 150,000 light-years across, and a hundred billion more galaxies spread across a vast cosmos.

The next time you're out under the stars, look up and think carefully about the enormity of the universe. It is one of the great humbling feelings of humanity.



OUR SOLAR SYSTEM

Realms of fire and ice

We start your tour of the cosmos with gas and ice giants, a lot of rocks, and the only known abode for life. by Francis Reddy

The cosmic distance scale

It's hard to imagine just how big our universe is. To give a sense of its vast scale, we've devoted the bottom of this and the next four stories to a linear scale of the cosmos. The distance to each object represents the amount of space its light has traversed to reach Earth. Because the universe is expanding, a distant body will have moved farther away during the time its light has traveled. To show the entire cosmos in 30 pages, we had to use a scale of 1 inch = 55.3 million light-years, or 1 millimeter = 2.18 million light-years.

OBJECT	DISTANCE
Sun	8.3 light-minutes
Jupiter	43.3 light-minutes
Saturn	79.3 light-minutes
Pluto	329 light-minutes
Oort Cloud	~1 light-year
Orion Nebula	1,350 light-years
Eta Carinae	7,500 light-years
Omega Centauri	17,000 light-years
Milky Way's center	27,200 light-years
Large Magellanic Cloud	160,000 light-years
Small Magellanic Cloud	200,000 light-years
Andromeda Galaxy (M31)	2.5 million light-years
Centaurus A	12 million light-years
Whirlpool Galaxy (M51)	26 million light-years
Virgo Cluster	55 million light-years

A cosmic perspective is always a little unnerving. For example, we occupy the third large rock from a middle-aged dwarf star we call the Sun, which resides in a quiet backwater of a barred spiral galaxy known as the Milky Way, itself one of billions of galaxies. Yet at the same time, we can take heart in knowing that our little tract of the universe remains exceptional as the only place where we know life exists. Our solar system hosts one abode for life, Earth, but in decades to come we may learn of others — perhaps biological enclaves on Mars or Jupiter's moon Europa. Although our solar system likely is not unique in this respect, definitive evidence for life on worlds orbiting other stars will be harder to find.

All told, the solar system contains about 4 million trillion trillion pounds of material, or about 1.0013 solar masses. The number on the left side of the decimal is the mass of the Sun itself, and about 73 percent of what's on the right side is held in the giant planet Jupiter. The remainder includes everything else: Earth and the other planets, moons, dwarf planets, asteroids and comets of all sizes, as well as dust and icy grains. One could correctly describe our planetary system as consisting of Jupiter plus debris.

The star that brightens our days, the Sun, is the solar system's source of heat and light as well as its central mass, a gravitational anchor holding everything together as we travel around the galaxy. Its warmth naturally divides the planetary system into two zones of disparate size: one hot, bright, and compact, and the other cold, dark, and sprawling. Here's how it all fits together.

Francis Reddy *is the senior science writer for the Astrophysics Science Division at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

The hot zone

Light takes eight minutes, give or take a few seconds, to reach Earth from the Sun's surface. The average distance is 92.96 million miles (149.6 million kilometers). We've barely begun our tour of the solar system, and numbers using familiar units already are cumbersome. So astronomers devised the astronomical unit (AU; see "Solar system yardstick," p. 26) as a simpler way to express distances at the scale of planetary orbits. The average distance from Earth to the Sun represents 1 AU.

Mercury lies closest to the Sun, at an average distance of 39 percent of Earth's, but its eccentric orbit — the most elongated of all the eight major planets — means this number varies. At its greatest distance, called aphelion, Mercury is 0.467 AU from the Sun, and at its closest point,

Great Attractor 218 million light-years

Perseus Cluster 248 million light-years

Coma Cluster 319 million light-years

million light-years

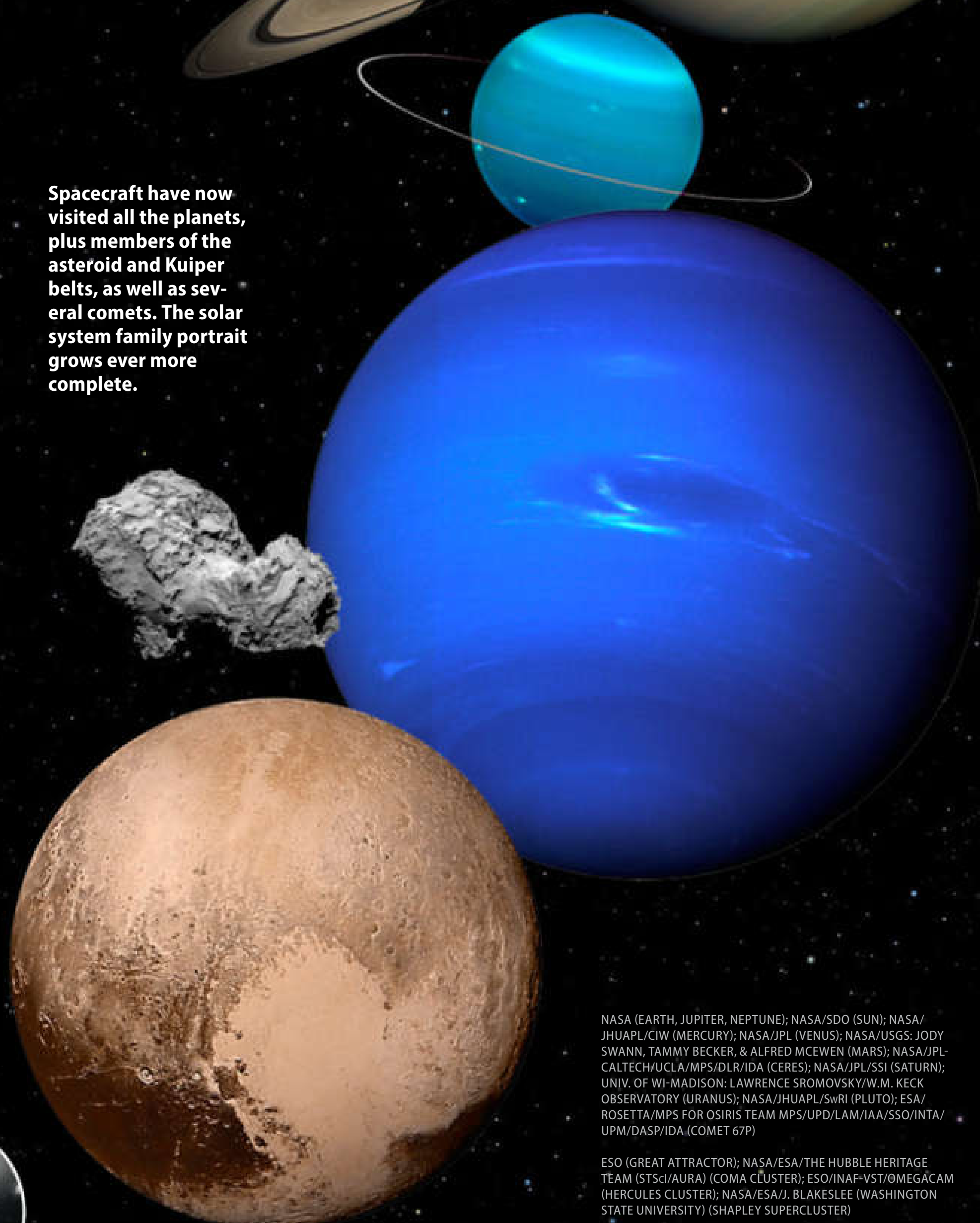
100 200 300 400

The cosmic distance scale

called perihelion, it's just 0.308 AU away. Standing on Mercury at this time, the Sun would appear 3.2 times larger than it ever appears from Earth. Surface temperatures reach 800° F (400° C), hot enough to melt lead. Baked by sunlight, pummeled by charged particles streaming from the Sun, and with just 38 percent of Earth's diameter, Mercury maintains only a wisp of an atmosphere. But a growing body of evidence suggests that despite its front-row seat in the solar system's hot zone, Mercury has ice.

In 1992, astronomers at Arecibo Observatory in Puerto Rico bounced radar off the planet's polar regions, revealing radar-reflective deposits on the floors of a few craters where daylight never shines. Decades earlier, astronomers had theorized that ice from comets and asteroids crashing on Mercury could find their way to "cold traps" in permanently shadowed polar craters. Data collected by NASA's Mercury-orbiting MESSENGER spacecraft in 2012 confirmed that these craters contain hydrogen-rich layers consistent with the presence of water ice. A similar process appears to have preserved subsurface ice in the Moon's polar areas.

Next out is Venus, a planet 95 percent of Earth's size and likewise a good match in properties like mass, density, gravity,



Spacecraft have now visited all the planets, plus members of the asteroid and Kuiper belts, as well as several comets. The solar system family portrait grows ever more complete.

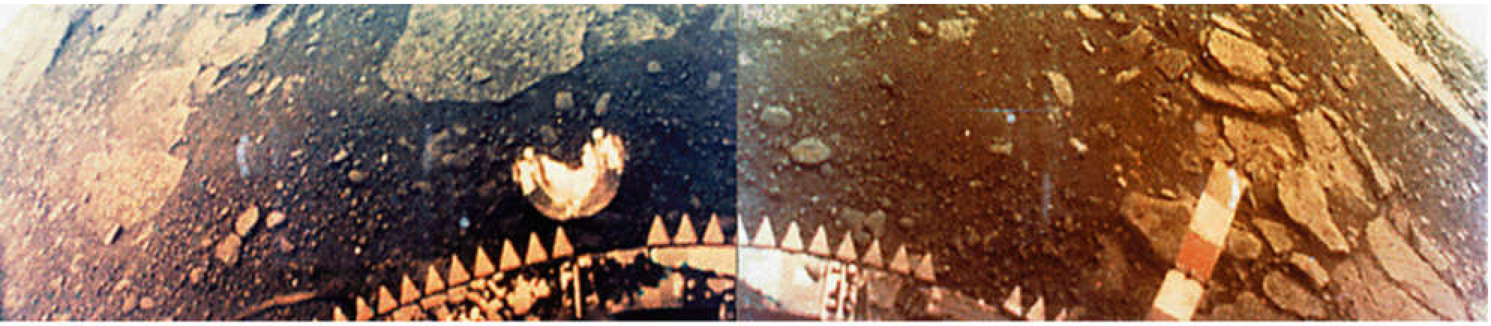
NASA (EARTH, JUPITER, NEPTUNE); NASA/SDO (SUN); NASA/JHUAPL/CIW (MERCURY); NASA/JPL (VENUS); NASA/USGS: JODY SWANN, TAMMY BECKER, & ALFRED MCEWEN (MARS); NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA (CERES); NASA/JPL/SSI (SATURN); UNIV. OF WI-MADISON: LAWRENCE SROMOVSKY/W.M. KECK OBSERVATORY (URANUS); NASA/JHUAPL/SwRI (PLUTO); ESA/ROSETTA/MPS FOR OSIRIS TEAM MPS/UPD/LAM/IAA/SSO/INTA/UPM/DASP/IDA (COMET 67P)

ESO (GREAT ATTRACTOR); NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA) (COMA CLUSTER); ESO/INAF-VST/OMEGACAM (HERCULES CLUSTER); NASA/ESA/J. BLAKESLEE (WASHINGTON STATE UNIVERSITY) (SHAPLEY SUPERCLUSTER)

Hercules Cluster
501 million light-years

Shapley Supercluster
586 million light-years

500 600 700 800 900



The Soviet probe Venera 13 holds the record at 2 hours, 7 minutes for the longest spacecraft to survive on the surface of Venus. It sent back pictures of its basalt-like surroundings, with the spacecraft itself partially visible at the bottom of the image. NASA HISTORY OFFICE

SOLAR SYSTEM YARDSTICK

After Copernicus placed the Sun at its center, astronomers had a solid sense of the relative dimensions of the solar system. They knew, for example, that Venus orbited 30 percent closer to the Sun than Earth. But they had no way of putting everyday measurements to these distances. In effect, the astronomical unit (AU; average Earth-Sun distance) was a yardstick with no markings.

In 1663, the Scottish mathematician James Gregory described a way to use transits — the apparent passage of Mercury or Venus across the Sun's face — to determine the AU's value. But efforts to use Mercury transits and other techniques, such as observing Mars at opposition, produced inconsistent results.

Edmond Halley, famous today as the first to predict the return of a comet, showed in 1716 that Mercury was too far from Earth for transit measurements to be effective, but Venus was ideal. He proposed a plan for observations of the 1761 Venus transit and suggested that astronomers be dispatched across the globe to observe and time the event. He believed the technique could establish the length of the astronomical yardstick to an accuracy of 0.2 percent.

It proved far more difficult in practice. To reach even 4 percent of the current value, astronomers had to combine the results of Venus transits in 1761 and 1769 — though this was still a huge improvement in accuracy. By the time the next transit rolled around, in 1874, astronomers had begun exploring more promising techniques, such as photographic observations of Mars.

We now can measure the distances to Venus, Mars, asteroids, and many other solar system objects by pinging them with radar. By sending a pulse of energy from a radio telescope and knowing the speed of light, the time taken for the signal to return provides the distance. Today astronomers define the AU as equal to 92,955,807.273 miles (149,597,870.700 kilometers). — *F. R.*

and composition. Yet with an average surface temperature of 864° F (462° C) day and night, Venus stays hotter than Mercury gets on its worst day despite its greater distance of 0.72 AU. The reason is the planet's dense atmosphere, which is composed almost entirely of heat-trapping carbon dioxide gas. Compounding the lack of hospitality, the surface pressure of the atmosphere is about 92 times sea-level pressure on Earth, the same we would experience at a depth of 3,000 feet (1,000 meters) under the ocean.

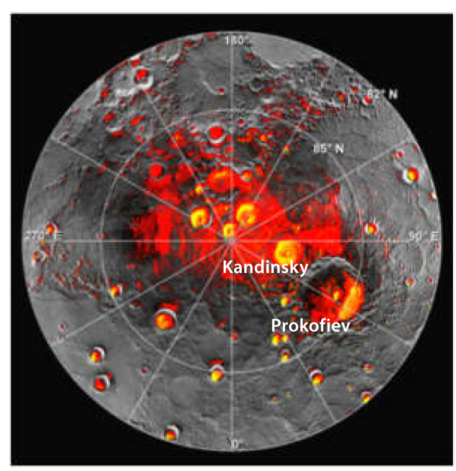
Unsurprisingly, no spacecraft landing on our inner neighbor has continued to transmit for much more than two hours.

Radar mapping of Venus from Earth and from orbiting spacecraft shows a world of fascinating geography. It is the only other planet in the solar system known to host active volcanoes. In 2015, scientists studying thermal imaging by the European Space Agency's (ESA) Venus Express orbiter reported 1,530° F (830° C) hot spots along the planet's Ganiki Chasma rift zone, a type of feature associated with terrestrial volcanism. Researchers have observed episodes where the temperatures of these spots abruptly increase and then cool down, suggesting ongoing eruptions.

Goldilocks zone

Next out is Earth, home sweet home and the only planet in the solar system where liquid water freely exists on the surface. As far as we know, the presence of water is a necessity for life. Astronomers extend this concept to define a star's "habitable zone" — a range of orbital distances where liquid water potentially could exist — as a way to identify exoplanets that may be capable of supporting life as we understand it. While we can quibble with the definition — perhaps there's a biology that uses solvents other than water or maybe life can develop entirely beneath the surface — it's a place to start. For the solar system, conservative values place the habitable zone between 0.99 and 1.69 AU. More optimistic values extend it in both directions, from 0.75 to 1.84 AU. Either way, the zone excludes desiccated Venus but includes Mars, thought to be warmer and wetter in the distant past.

Located about 1.5 AU out, Mars long has been viewed as the best bet for finding life in the solar system. But with half Earth's size and only 38 percent of its surface gravity, the Red Planet was crippled in its ability to hold onto the thick atmosphere needed to maintain surface water. In its first billion years, the upper layers of the atmosphere slowly bled into space, and occasional asteroid impacts drove away great masses of martian



NASA/JHUAPL/CIW

Mercury holds highly reflective material in its permanently shadowed craters that could be water ice, as revealed here by NASA's MESSENGER spacecraft and Earth-based radar mapping.

Boötes Supercluster
936 million light-years

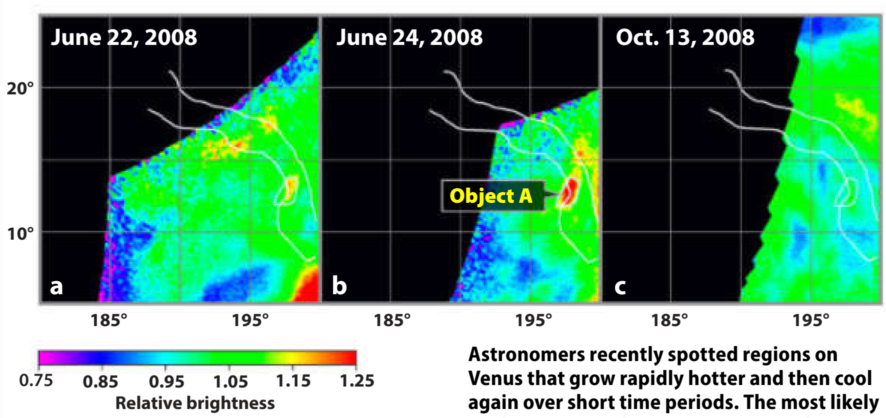
NASA (BOÖTES SUPERCLUSTER)

billion light-years

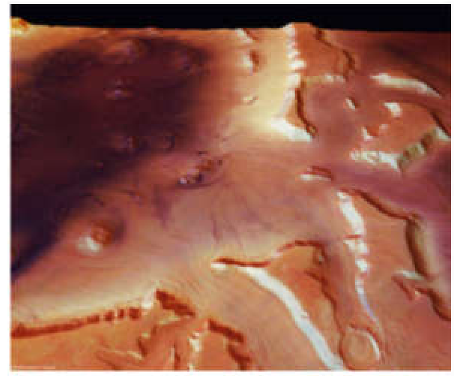
1 **1.25**

Our planet Earth is now under observation by DSCOVR, a joint project by NASA, the U.S. Air Force, and the National Oceanic and Atmospheric Administration, designed to monitor the solar wind in real time. Visually stunning images like this one, taken from a million miles away, are a bonus. NASA

Venusian hot spot



Astronomers recently spotted regions on Venus that grow rapidly hotter and then cool again over short time periods. The most likely explanation is volcanic eruptions on the planet's surface. E. SHALYGIN, ET AL. (2015)



The bases of mesas in Deuteronilus Mensae on Mars exhibit strange textures. Astronomers think they could have formed from the rapid melting of ice that lurks under the dust and rock currently overlaying the features. ESA/DLR/FU BERLIN (G. NEUKUM)

air. Once the atmosphere was thin enough, Mars cooled, and its water froze into the glaciers and ice caps we see there now. Today, the average atmospheric pressure is 0.6 percent that at Earth's mean sea level.

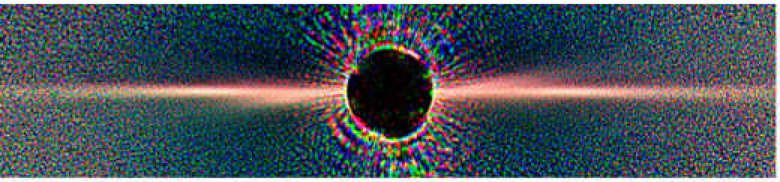
Near the winter pole, temperatures reach –195° F (–126° C) — so cold that roughly 30 percent of the carbon dioxide atmosphere snows out there, covering the surface with a dry ice veneer. While only the south pole contains a permanent dry ice component, water ice resides in both poles in the form of polar layered deposits, which, thanks to extensive spacecraft mapping, provide a minimum inventory of the planet's water ice content. If melted, the water in these deposits would cover an idealized smooth Mars in a liquid layer 69 feet (21 meters) deep. According to recent studies, the planet may have hosted a sea containing more water than the Arctic Ocean about 4.3 billion years ago. This would have formed a global water layer at least 6.5 times deeper than today's polar deposits could provide.

Mars may yet have its day in the Sun. Our star's luminosity is gradually increasing, which pushes the habitable zone outward. In about a billion years, the habitable zone will leave Earth roasting outside its inner edge. But the Red Planet will experience a more temperate period lasting a few billion years as the Sun transitions into its red giant phase. For Mars, summer is coming — though since much of its water has been lost to space through the years, it may not grow much more hospitable.

The rocks

Next comes the asteroid belt, which, along with the Kuiper Belt beyond Neptune, is a remnant of the disk of rocky and icy debris that gave rise to our planetary system. Contrary to Hollywood imaginings, the asteroid belt is mainly space. The main belt totals less than 5 percent the mass of Earth's Moon, and about a third of this is contained in Ceres, the largest object and the only dwarf planet in the asteroid belt. Add in Vesta, Pallas, and Hygiea, the next three largest asteroids, and half the belt's mass is accounted for.

The main belt starts at 2.06 AU, where objects make four orbits around the Sun in the time it takes Jupiter to make one. Astronomers call this a 4:1 orbital resonance. Whenever an asteroid's orbital period is a whole number fraction of Jupiter's orbital period, the giant planet easily destabilizes the tiny rock, quickly — on astronomical timescales — clearing it out of its original orbit. The 2:1 resonance

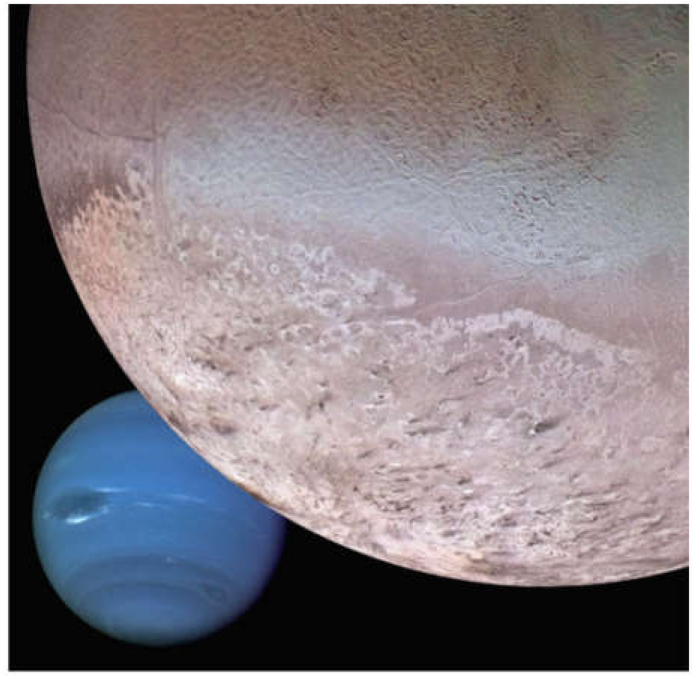


The disk around the star Beta Pictoris is similar to our own Kuiper Belt, rich in dust and debris left over from the solar system's birth. NASA/ESA/D. GOLIMOWSKI AND H. FORD (JHU)/D. ARDILA (IPAC)/J. KRIST (JPL)/M. CLAMPIN (GSFC)/G. ILLINGWORTH (UCO/LICK)/ACS SCIENCE TEAM

ACTIVE ASTEROIDS

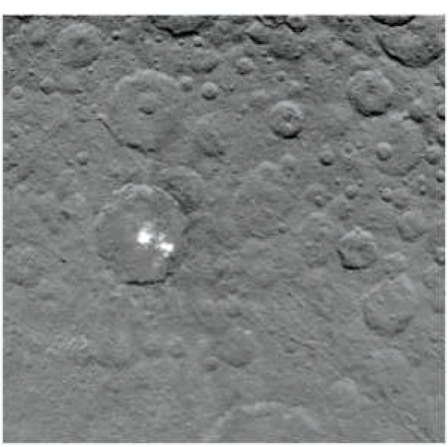
In the past decade, astronomers have recognized a population of asteroids that are losing mass, sometimes looking distinctly like comets. They include Ceres, Scheila, and Phaethon, the source of particles producing the Geminid meteor shower each December.

According to David Jewitt at the University of California, Los Angeles, who has been studying these objects, different processes may be responsible in each. A collision with a small asteroid tens of meters across is the best explanation for Scheila's outburst in 2010. Astronomers have reported water vapor in the spectrum of Ceres, where true comet-like activity may be occurring. The 2009 outburst of Phaethon was likely an ejection of dust, possibly in response to the breakdown of surface rocks under intense heating at perihelion (just 0.14 AU), when temperatures approached 1,400° F (760° C). — *F. R.*



Neptune's largest moon, Triton, may be a captured Kuiper Belt object. Here, Neptune is shown in the background as an orbiting spacecraft might see it. Triton hosts ice volcanoes and streaks caused by winds blowing nitrogen frost across the rough surface. NASA/JPL/USGS

— twice around for every Jupiter orbit — marks the distant edge of the main belt, located at 3.27 AU. While the main belt accounts for the greatest density of asteroids, many follow orbits that stray outside it thanks to Jupiter's work. In the past decade, a dozen or so asteroids have caught the eye of astronomers for their peculiar activity (see "Active asteroids" above), showing we still have much to learn about the solar system's "rock belt."



NASA/JPL-CALTECH/UCLA/MPS/DLR/IDA

NASA's Dawn spacecraft observed bright spots on the dwarf planet Ceres, orbiting in the asteroid belt. These spots of salt or water ice have fascinated astronomers since the spacecraft first spotted them.

Beyond the wall

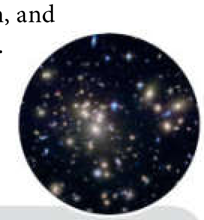
When comets head toward the Sun on the inbound legs of their elongated orbits, astronomers usually start seeing enhanced activity as they approach within 3 AU. This is the distance where exposed water ice rapidly begins sublimation, turning directly to a gas and powering jets that eject sunlight-reflecting dust into space. This seems as good a place as any to draw the line between the solar system's inner warmth and outer cold.

From here on out, the planets are giant worlds quite different in mass, density, and chemical composition from their siblings closer to the Sun, where warmer temperatures cooked away more volatile substances. Where the inner planets are built of rock and metal, the outer giants are massive worlds composed mainly of hydrogen, the lightest element. Jupiter, puppet master of the asteroid belt and the largest planet in the Sun's retinue, orbits at a distance of 5.2 AU. It holds 318 times Earth's mass and has 11 times its width. Saturn, not quite twice as distant at 9.6 AU, carries 95 times Earth's mass and is 9.5 times as wide.

Hydrogen makes up more than 90 percent of both planets by volume. Both planets also give off more heat than they receive from the Sun as they continue their gravitational contraction and cooling billions of years after they formed. Their atmospheres are essentially bottomless, transitioning from gaseous to liquid and even electrically conducting liquid forms of hydrogen with increasing depth. Depending on the details of how they formed, there may or may not be a solid core roughly the size of Earth. NASA's Juno orbiter, scheduled to arrive at Jupiter in July 2016, will measure the planet's gravitational field with sufficient accuracy to determine if a core exists.

A pair of slightly different giants lies farther out. Uranus, located at 19 AU, and Neptune, at 30 AU, have smaller hydrogen atmospheres making up less than 20 percent of their masses, which are 15 and 17 times Earth's, respectively. Instead, heavier elements dominate their bulk, with carbon, oxygen, nitrogen, and sulfur being likely candidates. Because scientists think the planets incorporated these chemicals as they accumulated frozen debris, Uranus and Neptune are sometimes called

3C 273 (quasar)
1.99 billion light-years

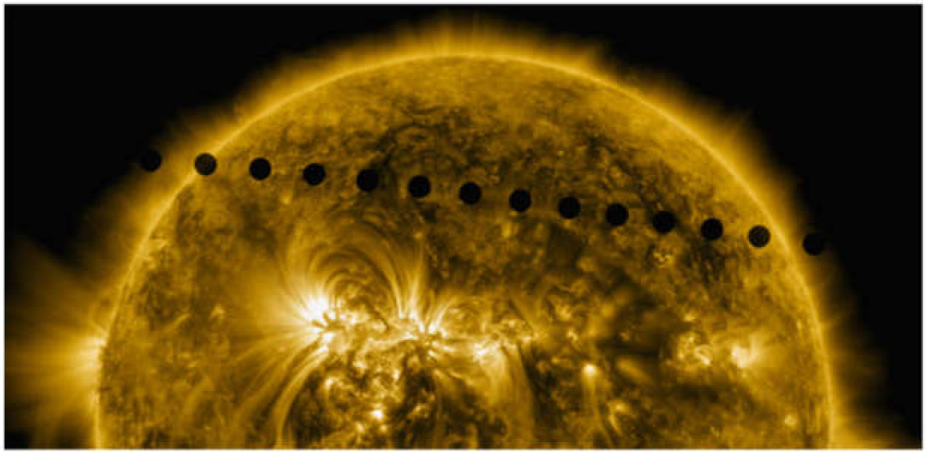


Abell 1689 (galaxy cluster)
2.27 billion light-years

billion light-years

2 **2.25**

With New Horizons' Pluto flyby in July, humans have now explored every object in the solar system that has, at least at some point, been classified as a planet. Pluto's moon Charon is shown as well, each of them to scale in both size and separation. NASA/JHUAPL/SWRI



NASA's Solar Dynamics Observatory captured the June 5, 2012, transit of Venus more than 250 years after astronomers' first attempt to use such a transit to measure the absolute distance scale of the solar system. NASA/GSFC/SDO

ESA/ROSETTA/NAVCAM

Comets like 67P/Churyumov-Gerasimenko, now under careful investigation by the European Space Agency's Rosetta spacecraft, might be swept into their extreme orbits after gravitational nudges from Jupiter or another large planet.

"ice giants." Both planets are about four times the size of Earth.

Icing over

The Kuiper Belt is a doughnut-shaped region located 30 to 50 AU from the Sun, and Neptune plays a key role in shaping it. In fact, astronomers think that Neptune's largest moon, Triton, may be a captured Kuiper Belt object (KBO). Like its rocky counterpart between Mars and Jupiter, the Kuiper Belt is a faint echo of the Sun's vast debris disk, the construction zone of our planetary system. In this region, orbits in favorable resonances can protect KBOs from disruptive encounters with Neptune. Pluto, at 39 AU, is the brightest of a KBO family locked in a 2:3 resonance, completing two orbits for every three trips Neptune takes around the Sun; stable groups also occupy other resonances. KBOs in resonances that are unfavorable are swept out of the belt, scattered by Neptune inward and outward onto more tilted and elongated orbits. Comets like 2P/Encke and 67P/Churyumov-Gerasimenko, subject of ESA's Rosetta orbiter, may have originated as fragments of scattered KBOs whose orbits were tightened up by encounters with Jupiter.

Now that its flyby of Pluto is complete, scientists hope NASA's New Horizons spacecraft will be able to provide close-up information on additional KBOs as it heads through the belt and out of the solar system. NASA's Voyager 1 spacecraft, now 132 AU out, has already done so in one sense. It has left the heliosphere, the magnetic bubble shaped by the outflow of charged particles from the Sun, and most of the particles now detected by the spacecraft have traveled to it from interstellar space. From Voyager 1's location, the Sun is a brilliant point about 24 times brighter than a Full Moon as seen from Earth. Still, the probe will take millennia to coast through the solar system's biggest structural component.

This is the Oort Cloud, where perhaps a trillion comets randomly orbit in a spherical shell centered on the Sun. It extends from 5,000 to 100,000 AU — that's 1.6 light-years, about 40 percent of the way to Proxima Centauri, the nearest star. Astronomers think the Oort Cloud formed early in the solar system's history, when icy objects much closer to the Sun were hurled outward by gravitational interactions with the planets. They now may take as long as 30 million years to complete an orbit. These comets are so feebly gripped by the Sun that other forces, such as the overall gravitational field of the galaxy's irregular mass distribution (known as the galactic tide) along with passing stars and massive molecular clouds, strongly affect them. Eventually these gravitational tugs can alter a comet's path so that it starts the long fall toward the Sun for the first time since it was cast out. These "dynamically new" comets travel on extremely elongated and randomly oriented paths. Gravitational interactions with the planets can divert them into shorter orbits, and astronomers think the famous Halley's Comet is one example.

At the fringes of the cloud, comets easily escape into interstellar space via the same tugs that nudge them sunward. Comets from our solar system already may have raced around another star. Might we one day see a comet from an alien Oort Cloud, another star's realm of ice? As far as astronomers know, it hasn't happened yet, but it's definitely possible.

Abell 1687 (galaxy cluster)
2.40 billion light-years

2.5

NASA/ESA/HUBBLE (3C 273); NASA/ESA/N. BENITEZ (JHU), ET AL./ACS SCIENCE TEAM (ABELL 1689); DSS (ABELL 1687)

THE MILKY WAY

Earth's home galaxy

Giant clouds of gas and dust sprinkled with splashy star clusters adorn the Milky Way's spiral arms, while the galaxy's vast halo teems with darker matter. by Francis Reddy

SOONER OR LATER ON ANY CLEAR, DARK NIGHT, AN ETHEREAL BAND CALLED THE MILKY WAY ARCHES ACROSS THE SKY. Although recognized since antiquity, philosophers and scientists could only guess at what it represented until fairly recently (see "How the Milky Way Galaxy got its name," p. 33). With the invention of the telescope, it became clear that the Milky Way was the collective glow of stars too faint to be seen by the naked eye. More than a century later, English astronomer Thomas Wright suggested that this glowing band was precisely what one would expect to see if the Sun were embedded in a flat disk of stars.

We now know that the Milky Way is the primary structure of our galaxy seen edgewise. Additional detail and especially the physical scale of the galaxy took another two centuries to work out. The process continues today as astronomers wrestle with conflicting evidence and make new discoveries. Much like mapping a fogbound city from a single intersection, scientists must decipher the galaxy's structure while viewing it from inside a disk where dust clouds dim and block starlight.

The true scale of the Milky Way Galaxy — and, indeed, the universe as a whole — became dramatically clearer in the 1920s. That's when a new generation of large telescopes coupled with photography revealed that "spiral nebulae" were actually entire galaxies like our own — "island universes" in the evocative parlance of the time. Surveys showed that most disk-shaped galaxies possessed winding spiral arms where young stars, gas, and dust were concentrated. Astronomers assumed our galaxy was a spiral too. In the 1950s, radio telescopes produced the first crude maps of the Milky Way's spiral arms by tracking how gas clouds moved around the galaxy.

Over the past two decades, surveys using dust-penetrating infrared light have brought the general picture of our galaxy into better focus. These projects include the ground-based Two Micron All-Sky Survey and Sloan Digital Sky Survey (SDSS) as well as two NASA spacecraft, the Wide-field Infrared Survey Explorer (WISE) and the Spitzer Space Telescope. These observations have helped astronomers better define our galaxy's spiral arms, take a census of star clusters and other phenomena in

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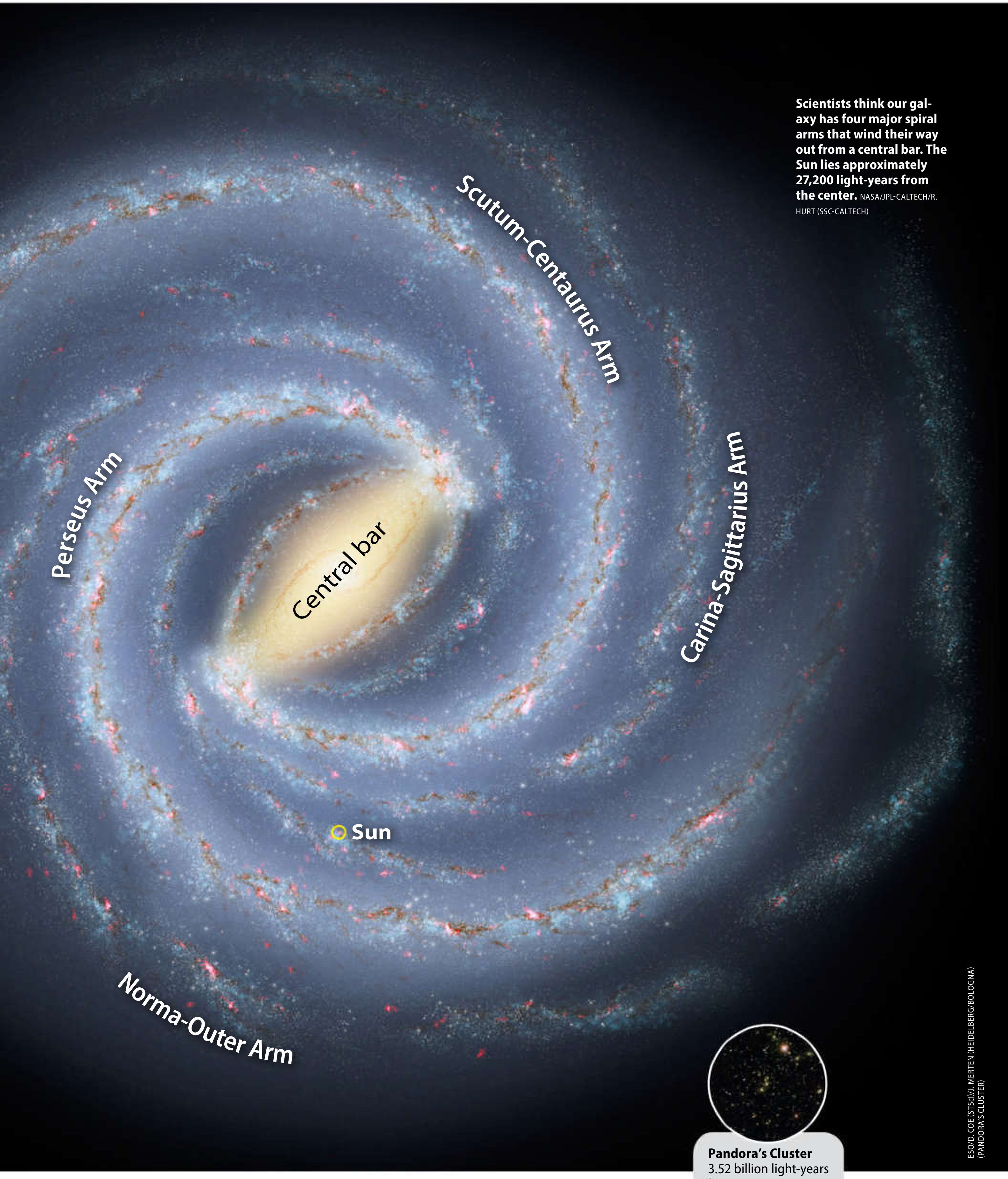
Francis Reddy *is the senior science writer for the Astrophysics Science Division at NASA's Goddard Space Flight Center in Greenbelt, Maryland.*

FAST FACT

27,200

LIGHT-YEARS

The Sun's distance from the galaxy's center



Scientists think our galaxy has four major spiral arms that wind their way out from a central bar. The Sun lies approximately 27,200 light-years from the center. NASA/JPL-CALTECH/R. HURT (SSC-CALTECH)

Pandora's Cluster
3.52 billion light-years

ESO/D. COE (STSCI)/J. MERTEN (HEIDELBERG/BOLOGNA) (PANDORA'S CLUSTER)

3.25

3.5

The Carina Nebula (NGC 3372) ranks among the Milky Way's biggest stellar nurseries. It lies about 7,500 light-years from Earth and burst to life when its first stars ignited some 3 million years ago. Today, it holds nine stars with luminosities at least a million times that of the Sun. NASA/ESA/N. SMITH (UCB)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

The Pleiades star cluster (M45) resides 440 light-years from Earth in the constellation Taurus. A prototypical open cluster, it spans about 15 light-years and holds some 500 stars. These luminaries will disperse over the next few hundred million years. NASA/ESA AND AURA/CALTECH

dust-obscured regions of the disk, and reveal that the central component of our galaxy, called its "bulge," is really a vast football-shaped star cloud seen nearly end on. This discovery resulted in a classification change for the Milky Way from spiral galaxy to barred spiral galaxy.

Several ambitious and complementary projects now aim to provide a true 3-D portrait of our galactic home. The European Space Agency's Gaia spacecraft, which was launched in 2013, should return position and motion information of unprecedented accuracy for roughly a billion stars.

But Gaia largely covers optical wavelengths, which means that intervening dust clouds limit how deeply it can probe into the galaxy's disk. Dust doesn't affect radio wavelengths, and a facility called the Very Long Baseline Array (VLBA) can measure distances and motions to a small number of sources more accurately than Gaia. By linking 10 radio dishes located from Hawaii to St. Croix so they function as a single telescope, the VLBA has the greatest resolving power available to astronomy. Two projects, the Bar and Spiral Structure Legacy (BESSEL) survey and the VLBI Exploration of Radio Astrometry (VERA), are using this capability to pinpoint the locations and motions of regions where new stars are forming in order to trace our galaxy's spiral structure.

Movin' out

The frontier of the galaxy lies at the outer fringe of the Oort Cloud of comets, about 100,000 astronomical units (AU; the average Earth-Sun distance) or 1.6 light-years away (see "From AU to light-year," p. 34). Here, the Sun's gravitational pull weakens to the level of nearby stars, and comets whose orbits take them this far may drift out of the Sun's grasp entirely. Although the nearest star today is Proxima Centauri, 4.22 light-years away, other stars played this role in the past and will do so in the future.

All stars orbit the center of the galaxy, but these orbits are more elliptical and more tilted than planetary orbits in the solar system. The Sun now lies about 27,200 light-years from the Milky Way's center — more than one-third of the way into the disk — and roughly 90 light-years above the galaxy's midplane. During each orbit, which takes about 240 million years to

3C 48 (quasar)
4.05 billion light-years

billion light-years

3.75 **4**

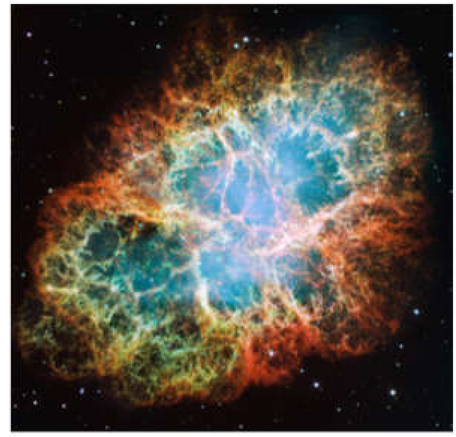
HOW THE MILKY WAY GALAXY GOT ITS NAME

Spend some time under the stars any clear night far from city lights, and a ghostly band called the Milky Way eventually will come into view. Flecked with some of the brightest stars in our galaxy and cleaved by intervening dust clouds for about a third of its extent, the Milky Way has been recognized since antiquity. In mythology, it was frequently associated with a cosmic pathway or heavenly stream.

The ancient Greeks called it *galaxías kýklos*, the "milky circle," a description that also gave rise to our word "galaxy." The Romans lifted the concept but gave it a twist appropriate for a civilization fond of road construction, calling it *via lactea*, the "milky way." Galileo Galilei took the first step in understanding what it actually represented in 1610, when his new and improved spyglass revealed that the pale light came from individual faint stars "so numerous as almost to surpass belief."

Over the next two centuries, as astronomers began to understand that the Milky Way was part of an "island universe" that included the Sun and other visible stars, the name for a mythical cosmic pathway was transferred to our galactic home. — *F. R.*

At a distance of 1,350 light-years, the Orion Nebula (M42) is the nearest large star-forming region. Our Sun likely formed in a cloud like this, one capable of producing 1,000 to 10,000 stars. NASA/ESA/M. ROBBERTO (STScI/ESA)/THE HST ORION TREASURY PROJECT TEAM



Massive stars live fast and die young, exploding as supernovae and leaving behind remnants like the Crab Nebula (M1). Such star death often triggers future star formation as shock waves compress surrounding gas. NASA/ESA/J. HESTER AND A. LOLL (ASU)

complete, the Sun's position oscillates above and below the galactic plane. Other stars in our vicinity follow slightly different paths, which means that the distribution and composition of our stellar neighborhood gradually changes. Stars routinely pass much closer to the Sun than Proxima Centauri is now.

For example, in 2014, astronomer Ralf-Dieter Scholz of the Leibniz Institute for Astrophysics in Potsdam, Germany, discovered that a faint M dwarf star detected by WISE was about 20 light-years away, making it a previously unknown close neighbor. A team led by Eric Mamajek at the University of Rochester in New York noticed that "Scholz's Star," which is actually a binary, shows little motion across the sky but rapid motion directly away from us, suggesting it might have grazed the solar system.

The study reveals that the binary passed well inside the Oort Cloud, coming within 52,000 AU about 70,000 years ago, and now holds the record for the closest flyby of any known star. It will take about 2 million years for any comets dislodged by this passage to reach planetary orbits, but the system's low mass — just one-sixth the Sun's — and its path through the outer Oort Cloud argue against any significant comet enhancement.

Dim, low-mass M dwarfs like Scholz's Star and Proxima Centauri actually typify the Milky Way's stellar population. Most of the galaxy's roughly 400 billion stars are likely M dwarfs, but because they emit little visible light, we're still finding those close to the solar system through infrared surveys like WISE. For stars, mass is destiny. M dwarfs may be dim, but their low masses mean they burn their nuclear fuel sparingly and will keep shining billions of years after the Sun dies.

Some stars barely shine at all. They never generate energy in their cores though true hydrogen fusion, the power source that heats stars for most of their lives, but when young they can produce energy by fusing a rare form of hydrogen, deuterium. Called brown dwarfs, they measure between 1.2 and 7 percent of the Sun's mass. The companion to Scholz's Star is a member of this class. With surface temperatures as cool as one-tenth the Sun's, brown dwarfs are marginal stars that may be as numerous as the real things. More than 50 known stars and brown dwarfs reside within 16 light-years of the Sun, but only 10 of them are visible to the naked eye.

FAST FACT

150,000

LIGHT-YEARS

Diameter of the galaxy's disk

The night sky distorts our picture of the galaxy's stars in another way, too. Of the 100 brightest stars in the sky, a third lie within 100 light-years. These include Sirius, the night sky's brightest, 8.6 light-years away; Procyon, 11 light-years away; Vega and Fomalhaut, both 25 light-years off; Castor (52); Aldebaran (65); and Regulus (77). But another third lie more than 400 light-years away, including Polaris (430), Antares (600), Betelgeuse (640), Rigel (860), and Deneb (2,600). All these stars have masses more than seven times the Sun's and are tens of thousands of times more luminous. Consequently, they burn through their hydrogen fuel at a faster clip. Long before our Sun's fires quench, these stars will end their days in spectacular supernova explosions.

From stars to clusters

Going further up the mass scale results in an ever-dwindling number of stars, and not just because the most massive ones are so short-lived. Stars are born in dense, cold molecular clouds. Once a massive star forms, its intense ultraviolet light and a powerful outflow called a stellar wind start to disperse the birth cloud, limiting the number of other massive stars able to form nearby. Only a few dozen stars in the Milky Way have energy outputs exceeding a million times the Sun's. Topping the list are WR 25 and Eta Carinae, two massive

NASA/ESA/NICMOS (3C 48)

4.25

4.5

Sagittarius A*, the bright spot at the heart of the luminous cloud at center, glows strongly in X-rays as matter swirls into the maw of a 4-million-solar-mass black hole. This supermassive object lies 27,200 light-years from Earth and is the gravitational hub of our galaxy. NASA/CXC/UNIVERSITY OF WISCONSIN/Y. BAI, ET AL.

FROM AU TO LIGHT-YEAR

Where the solar system ends, interstellar space and the galactic frontier begin. At the fringe of the Oort Cloud, perhaps 100,000 astronomical units (AU; the average Earth-Sun distance) away, comets are about as likely to be dislodged from the solar system as to continue in their slow orbits. From here on out, expressing distances in the manner commonly used within the solar system rapidly becomes unwieldy. It turns out that 63,241 AU equals the distance light travels in a vacuum over the course of one year: a light-year. The fringe of the Oort Cloud is about 1.6 light-years away. The closest star, Proxima Centauri, is a mere 4.22 light-years distant. And the Orion Nebula, the closest large star-forming region, is about 1,350 light-years off.

According to relativity, no matter or information can travel faster than the speed of light in a vacuum. But there is a consequence to thinking about distance in terms of light travel time. The farther away we look, the longer light takes to reach us. At any given moment, we see Proxima Centauri as it looked 4.22 years ago and young stars in the Orion Nebula as they appeared more than a millennium ago. Applied to large numbers of galaxies at different distances, this time-machine effect gives astronomers a powerful tool for understanding how galaxies like our own developed and evolved over billions of years. — *F. R.*

binary systems located about 7,500 light-years away and shining with 6.3 million and 5 million solar luminosities, respectively. Another eight stars in the Carina Nebula make the cut as well, and seven more occur in a stellar grouping called the Cygnus OB2 association.

Massive stars play a powerful role in mapping out our galaxy's spiral arms. They can be seen across great distances, they explode before wandering too far from their stellar nurseries, and they can light up their dissolving birth clouds and excite molecules within them, like water and methanol. Under the right conditions, which are common in star-forming regions, these molecules can become masers — the microwave equivalent of lasers — and beam amplified radio waves our way, creating beacons that cut through starlight-blocking dust clouds.

Star groupings of various types also help trace galactic structure. OB associations are loose collections of between 10 and several hundred hot, young, and massive O- and B-type stars spanning up to a few hundred light-years. The nearest is the Scorpius-Centaurus OB2 association, which lies about 470 light-years away and boasts the red supergiant Antares among its members. Its oldest subgroup was born roughly 15 million years ago, and shock waves from a supernova helped trigger star formation in a neighboring cloud about 5 million years ago.

Open star clusters, such as the Hyades and Pleiades in Taurus (150 and 440 light-years away, respectively) and the Beehive in Cancer (about 580 light-years distant), are relatively compact collections of stars that formed together within the same molecular cloud. These clusters contain anywhere from dozens to hundreds of stars in a region less than about 50 light-years wide, and they will gradually disperse over a few hundred million years. Astronomers have cataloged about 1,200, though the Milky Way may contain as many as 100,000.

In places like the Orion Nebula and the Eagle Nebula (1,350 and 7,000 light-years away, respectively), where young stars have emerged from their birth clouds and set them aglow, scientists are seeing the creation of new open clusters less than 2 million years old. Young clusters can be detected in the infrared even before they break out of their natal cloud. Using data from WISE, a team led by Denilso Camargo at the Federal University of Rio Grande do Sul in Brazil reported in 2015 the discovery of hundreds of dust-shrouded clusters embedded deeply in their host molecular clouds.

OB associations, open clusters, and embedded clusters all reside in the Milky Way's disk. But globular clusters form a radically different kind of galactic tracer. Essentially giant star balls, these clusters pack tens of thousands to perhaps a million stellar siblings into spheres less than 300 light-years across. Our galaxy has fewer than 200, and all are more than 10 billion years old. Globular clusters orbit the galaxy's center, but they follow wildly inclined paths that take them far above and below the disk. Researchers now know that the Milky Way has pilfered at least some globular clusters, but more on that later.

Galactic architecture

Early in the last century, the differences between open and globular star clusters guided astronomers into an overview of the Milky Way. Open clusters orbit in a disk-shaped volume that also contains nearly all of the galaxy's gas and dust, the seed for new stars. This disk is some 1,000 light-years thick and extends probably 75,000 light-years from the galactic center, placing the solar system a little more than a third of the way out in the disk.

In the disk's center lies a football-shaped concentration of mainly old stars called the galactic bulge, which is about 12,000 light-years long. Although its exact size, shape, and viewing angle remain somewhat unclear, we see the bulge obliquely not too far from end on. Until recently, astronomers regarded the bulge as sort of a senior center for aging stars, a population that formed rapidly as the galaxy assembled through mergers with smaller galaxies some 10 billion years ago. Predominantly older stars do occupy parts of the bulge well above and below the disk,

billion light-years

4.75 5

but recent studies show a wide range of stellar ages, from 3 to 12 billion years, closer to the midplane. Various lines of evidence suggest the bulge population formed largely as a result of natural instabilities in the evolving disk.

At the center of the bulge is the galaxy's anchor, the object everything else orbits — a supermassive black hole weighing about 4 million solar masses. Regular monitoring of the galactic center shows that it often flares in X-rays — the signature of matter falling toward its doom — but this pales in comparison to what we know a monster black hole can do, and there is evidence it has been more active in the past. In 2010, data from NASA's Fermi Gamma-ray Space Telescope revealed ginormous gamma-ray-emitting bubbles reaching 25,000 light-years above and below the galactic center, likely the smoking gun of a powerful outburst millions of years ago.

The precise structure of the disk remains poorly known, including the number and position of its spiral arms. Recent radio studies of thousands of sources — stars in embedded clusters detected in the infrared, nebulae set aglow by young stars, giant molecular clouds, and water and methanol masers — seem to show that the Milky Way has four major spiral arms that originate near the galactic center and wind outward. In order from the center moving toward the Sun, they are the Norma-Outer Arm, the Scutum-Centaurus Arm, and the Carina-Sagittarius Arm. Farther out, we encounter the Perseus Arm, and farther still, the outer arc of the Norma-Outer Arm.

Astronomers long thought that the solar system resided in a starry spur located near the inner edge of the Perseus Arm. Yet one of the first surprising results from the BESSEL and VERA projects is that our "spur" is a significant structure, sporting as much massive star formation as the adjacent major arms. At this point, astronomers aren't sure whether to classify our local patch of the galaxy as a branch of the Perseus Arm or an independent segment.

And the disk holds more surprises. A 2015 study of SDSS data led by Yan Xu at the Chinese Academy of Sciences in Beijing has extended its size by about 50 percent over previous values. The number of stars in the disk had seemed to drop off around 50,000 light-years from the center, but then SDSS found what appeared to be a vast ring of stars about 10,000 light-years farther out. The new study shows this is an illusion caused by at least four ripples that displace stars in the disk above and below the galactic plane. When we look out of the galaxy from the solar system, the disk is perturbed up a few hundred light-years, then down, then up, and then down again, starting about 6,500 light-years from the Sun and reaching at least 50,000 light-years away. Additional ripples may yet be found.

FAST FACT

1.5 to 2

TRILLION SUNS

Galaxy's total mass (including dark matter)

Two million stars glow in the core of Omega Centauri, though this is just 20 percent of the globular cluster's total. Omega lies 17,000 light-years away and likely is the bulge of a disrupted dwarf galaxy. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

What does the Milky Way look like from afar? From what we know, it resembles this barred spiral galaxy, UGC 12158. This island universe spans about 140,000 light-years and lies some 400 million light-years away. ESA/HUBBLE AND NASA

Small galaxies orbiting our own may have produced the ripples. One in particular, known as the Sagittarius Dwarf Spheroidal, has passed through the disk multiple times and is gradually dissolving into streams of stars as it orbits the Milky Way. Like a stone tossed into still water, the gravitational effect of a satellite galaxy plunging through the disk could produce ripples. Simulations suggest that satellite galaxies tearing through the disk can play a role in creating spiral structure. And intriguingly, the newfound ripples align closely with the Milky Way's spiral arms.

The disk sits within a spherical volume called the galactic halo, a place ruled by globular clusters and satellite galaxies, as well as strewn with stars stripped from them. Our galaxy — indeed, most galaxies — may have been built by gobbling up many smaller galaxies. Today we see streams of stars linked to several small satellites, and the Milky Way appears to have swiped several globular clusters from the Sagittarius Dwarf Spheroidal. The largest and brightest globular cluster, named Omega Centauri and located about 17,000 light-years away, has a more complex stellar makeup than others. Researchers suspect it is the leftover bulge of a dwarf galaxy long ago shredded by our own.

Yet most of the Milky Way's mass remains unseen. The motions of stars around our galaxy and others reveal a gravitational influence extending far beyond the structures we can see. Studies show that the Milky Way resides in a roughly spherical halo of invisible material — called dark matter — reaching 900,000 light-years across, or about six times the disk's diameter. This stuff makes up 27 percent of the cosmos and created the gravitational infrastructure that coaxed ordinary matter into structures that eventually built galaxies like our own.

The current phase of galactic exploration already has provided major new insights, but many questions remain. As astronomers consolidate the results of this research over the next decade, an accurate 3-D portrait of the Milky Way will emerge, enabling us for the first time to view our island universe in the same way we see other galaxies: as a complete cosmic object — a whole greater than the sum of its parts.

— The Cosmic Distance Scale continues on page 44

5.25

MARTIN RATCLIFFE and **ALISTER LING** describe the solar system's changing landscape as it appears in Earth's sky.

Visible to the naked eye
Visible with binoculars
Visible with a telescope

December 2015: A gemlike shower

A Geminid meteor shoots past Orion (lower center) shortly before dawn at the peak of the 2013 shower. Similarly Moon-free conditions bode well for this year's shower. TONY ROWELL

The morning sky sees most of the planetary action in December, with Venus, Mars, and Jupiter all prominently displayed. A highlight of the month occurs during daylight on the 7th when the Moon passes directly in front of Venus and hides it from view.

The evening sky possesses more subtle attractions. Uranus and Neptune remain binocular targets all month, while Mercury climbs into view during twilight after mid-December. But perhaps the month's biggest event comes on the 14th when the annual Geminid meteor shower peaks under a Moon-free sky.

Martin Ratcliffe *provides planetarium development for Sky-Skan, Inc., from his home in Wichita, Kansas. Meteorologist* **Alister Ling** *works for Environment Canada in Edmonton, Alberta.*

Let's begin our tour of the solar system shortly after the Sun goes down in the latter half of December. **Mercury** appears above the southwestern horizon starting about 30 minutes after sunset. On the 15th, it lies only 4° high but should show up because it shines so brightly, at magnitude –0.6. (Binoculars will help you to spot it in the twilight glow.)

The innermost planet remains within 0.1 magnitude of this benchmark for the rest of December but becomes significantly easier to see as it climbs away from the horizon. By the time it reaches greatest elongation on the 28th, when it lies 20° east of the Sun, Mercury stands 9° high a half-hour after sundown and doesn't set until an hour later. When viewed through a telescope in late December, the world shows a disk that measures 7" across and appears close to half-lit.

Keep your binoculars handy as the sky darkens, and you can put them to work tracking down the outer two major planets. **Neptune** lies farther west than Uranus and thus is closer to setting, so target it first. The ice giant planet lies in central Aquarius, a large and relatively inconspicuous constellation that appears nearly halfway from the southern horizon to the zenith as night falls. At midmonth, it sets after 10 P.M. local time.

The best guide star for finding Neptune is magnitude 4.8 Sigma (σ) Aquarii. If your sky is less than perfect, first locate magnitude 3.8 Lambda (λ) Aqr; Sigma lies 6° southwest of Lambda. Neptune appears in the same binocular field as Sigma all month. On the 1st, the planet resides 1.5° northeast of the star. The gap grows to 2.0° by month's end.

Neptune glows at magnitude 7.9, nearly 20 times dimmer than Sigma. You may have a hard time seeing this faint with hand-held binoculars. Mount them on a tripod, however, and you can easily view objects a full magnitude fainter. Although binoculars certainly can reveal Neptune,

Venus, Mars, and Jupiter stretch across the predawn sky on chilly December mornings. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

RISING**MOON**

A Christmas present at Luna's north pole

Whether Santa Claus delivers a new telescope or you use just your naked eyes, marvel at the Full Moon high in a late evening sky December 25. Chances are you'll feel there's something unusual about it. You're right. Mare Crisium on the eastern limb looks like it's nearly on the equator, and if you view through binoculars, the rays pointing back to Tycho reach near the southern limb. Plenty of "extra" light-hued terrain also appears near the north pole.

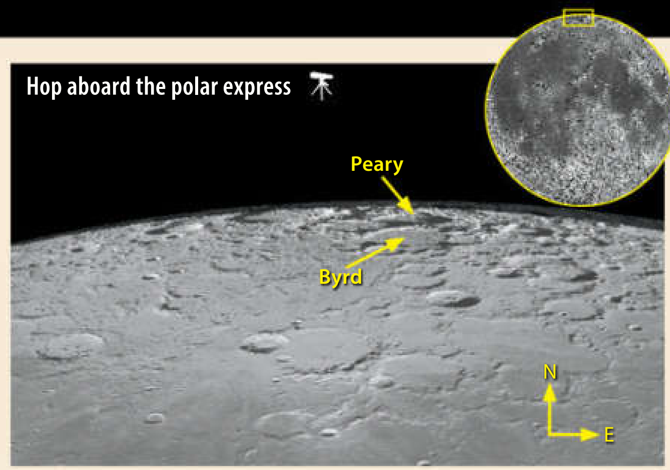
On the 25th, Luna lies about as far south of the ecliptic — Earth's orbital plane around the Sun — as it can get. From our earthbound perspective, we see a little past the north pole and down the farside in what astronomers call a northern libration.

If you're up for a little adventure, let's embark on a trek to the north pole.

Lunar cartographers named many features close to the pole after great polar explorers of past centuries. Two major craters honor the American adventurers Richard Byrd and Robert Peary. Like those pioneers, avoid eyestrain by using sunglasses or a filter to cut down on the Full Moon's glare. Look just below the northern limb for Byrd, which appears as a large, flat, and fully illuminated oval.

On the 25th, sunlight nicely illuminates this crater's back wall, which is almost indistinguishable from Peary's southern flank. The shadows help our minds generate a 3-D view of the polar regions. We can see over and past Peary's parapets into its partially shadowed floor right up to the back wall. Immediately behind that lies the north pole itself, which remains in shadow.

If you look carefully beyond Peary, you'll see another lit wall. This is the outer rim of Rozhdestvenskiy, a large crater named for Soviet physicist Dmitriy Rozhdestvenskiy. This feature lies at 87° north latitude on the lunar farside. Off to the east and down the limb a little ways, you'll find the crater walls of Nansen, named for the Norwegian polar explorer Fridtjof Nansen.



A favorable libration at Full Moon brings normally hidden craters at the lunar north pole into view. ALISTER LING, BASED ON CLEMENTINE DATA; INSET: NASA/GSFC/ASU

you might not be able to identify it unambiguously. To confirm a sighting, point your telescope at the suspected planet. Neptune will show a disk that measures 2.3" across and sports a blue-gray color.

Head 40° east of Neptune along the ecliptic — the apparent path of the Sun across the sky that the planets follow closely — and you'll reach **Uranus**. This ice giant world, a kissing cousin to Neptune, resides among the faint stars of Pisces the Fish. Uranus appears slightly more than halfway to the zenith in the southeast as darkness falls and remains on view all evening. It doesn't set until around 1 A.M. local time even as the month comes to a close.

The seventh planet shows up easily through binoculars. Glowing at magnitude 5.8, it is technically visible with naked eyes under a dark sky,

— Continued on page 42

METEORWATCH

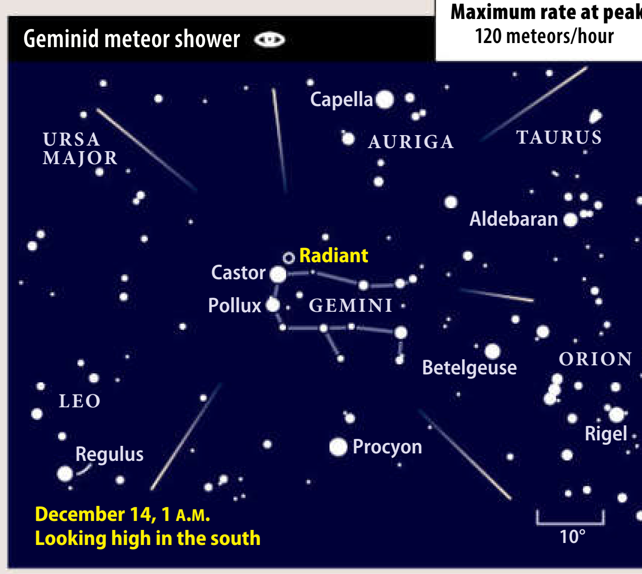
Absent Moon means magical meteor show

Meteor observers always look at the calendar to see which showers will occur near New Moon. Bright moonlight drowns out fainter meteors and renders the brighter ones less impressive. But no worries this month — the prolific Geminid shower peaks December 14, just three days after New Moon.

The "shooting stars" appear to radiate from a point near Castor in Gemini. The radiant climbs higher in the east throughout the evening and passes nearly overhead around 2 A.M. local time. Don't stare at the radiant, however — you'll see longer streaks if you look 40° to 60° away. For the best views, find an observing site far from the city, where you can expect to see up to 120 meteors per hour.

Geminid meteors

Active dates: Dec. 4–17
Peak: December 14
Moon at peak: Waxing crescent
Maximum rate at peak: 120 meteors/hour



One of this year's most prolific meteor showers could deliver up to 120 "shooting stars" per hour under ideal conditions.

OBSERVING HIGHLIGHT A waning crescent Moon passes directly in front of Venus during daylight hours December 7 for observers across North America.

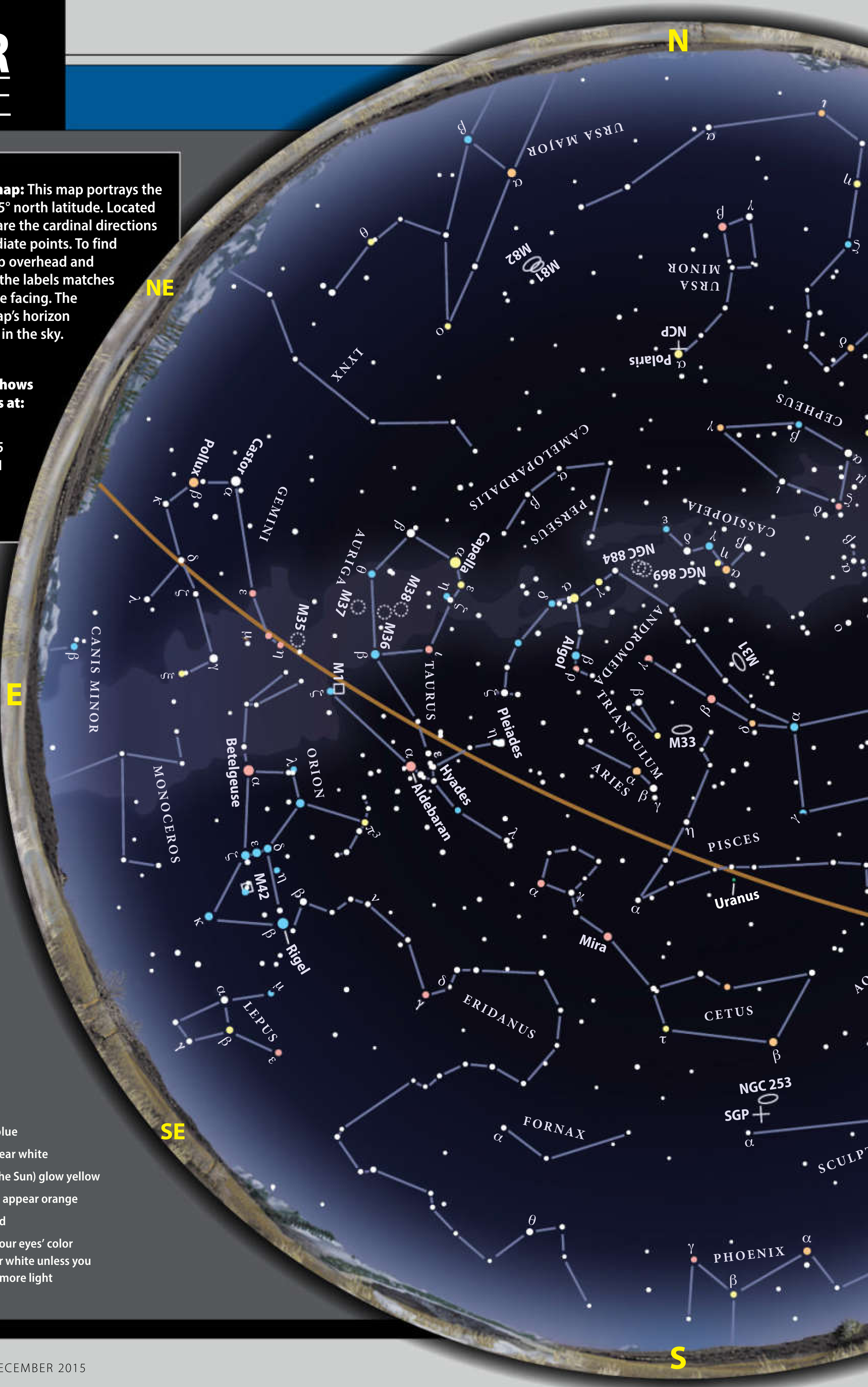
STAR DOME

How to use this map: This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. December 1
8 P.M. December 15
7 P.M. December 31

Planets are shown at midmonth



STAR MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

STAR COLORS

A star's color depends on its surface temperature.

- The hottest stars shine blue
- Slightly cooler stars appear white
- Intermediate stars (like the Sun) glow yellow
- Lower-temperature stars appear orange
- The coolest stars glow red
- Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

MAP SYMBOLS

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

DECEMBER 2015

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Calendar of events

3 Last Quarter Moon occurs at 2:40 A.M. EST

4 The Moon passes 1.8° south of Jupiter, 1 A.M. EST

5 The Moon is at apogee (251,531 miles from Earth), 9:56 A.M. EST

The Moon passes 0.1° south of Mars, 10 P.M. EST

7 The Moon passes 0.7° north of Venus, noon EST

9 Asteroid Psyche is at opposition, 9 A.M. EST

11 New Moon occurs at 5:29 A.M. EST

SPECIAL OBSERVING DATE

14 The annual Geminid meteor shower peaks under a Moon-free sky.

17 The Moon passes 3° north of Neptune, 3 A.M. EST

18 First Quarter Moon occurs at 10:14 A.M. EST

19 The Moon passes 1.2° south of Uranus, 8 P.M. EST

21 The Moon is at perigee (228,924 miles from Earth), 4:00 A.M. EST

Mars passes 4° north of Spica, 7 A.M. EST

Winter solstice occurs at 11:48 P.M. EST

23 The Moon passes 0.7° north of Aldebaran, 3 P.M. EST

24 Asteroid Euterpe is at opposition, midnight EST

25 Full Moon occurs at 6:11 A.M. EST

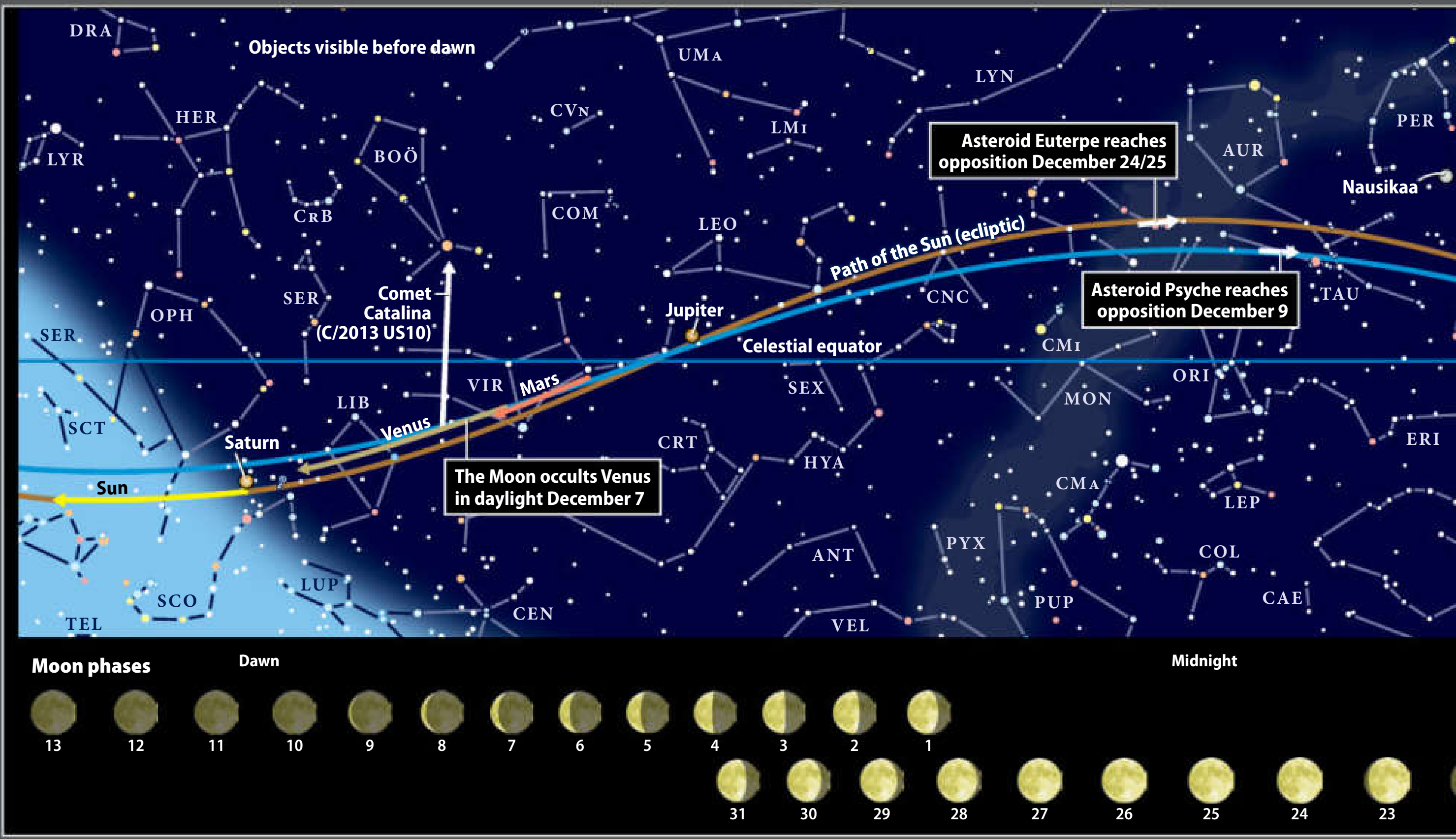
26 Uranus is stationary, 6 A.M. EST

28 Mercury is at greatest eastern elongation (20°), 10 P.M. EST

31 The Moon passes 1.5° south of Jupiter, 1 P.M. EST

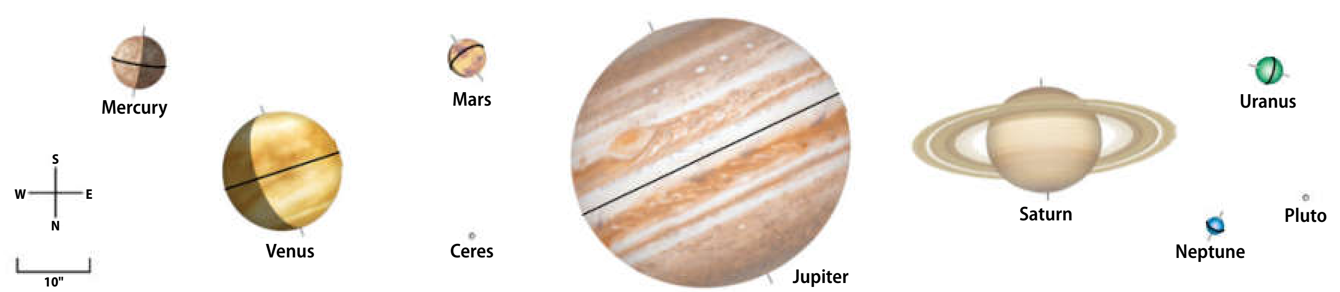
BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**

The planets in December 2015



The planets in the sky

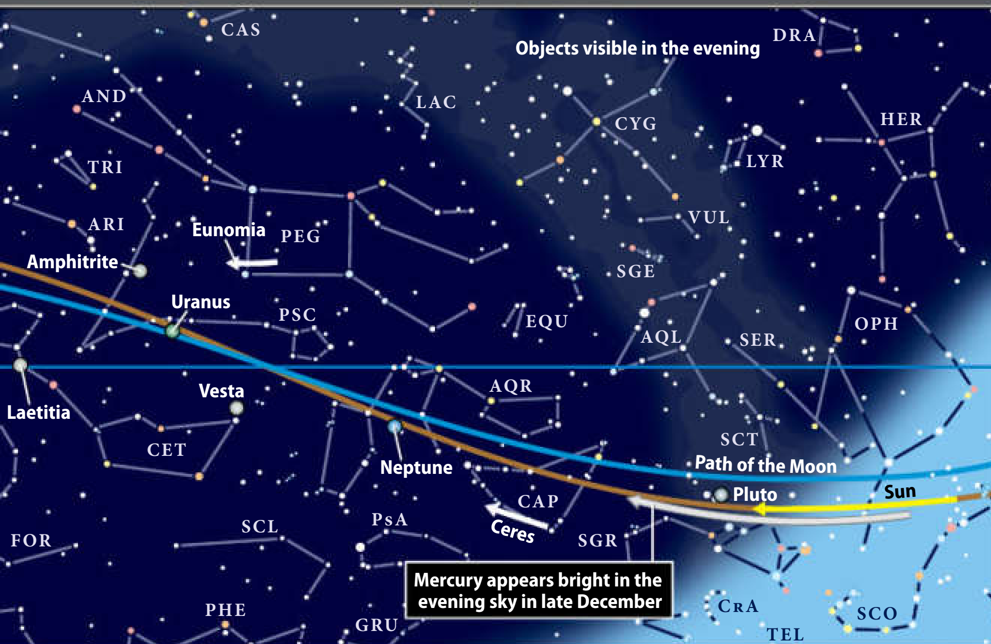
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets for the dates in the data table at bottom. South is at the top to match the view through a telescope.



Planets	MERCURY	VENUS	MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
Date	Dec. 31	Dec. 15	Dec. 15	Dec. 15	Dec. 15	Dec. 31	Dec. 15	Dec. 15	Dec. 15
Magnitude	–0.5	–4.1	1.4	9.3	–2.1	0.5	5.8	7.9	14.2
Angular size	7.1"	15.8"	5.1"	0.4"	37.1"	15.3"	3.6"	2.3"	0.1"
Illumination	53%	72%	92%	98%	99%	100%	100%	100%	100%
Distance (AU) from Earth	0.947	1.054	1.845	3.489	5.316	10.868	19.557	30.207	33.915
Distance (AU) from Sun	0.330	0.719	1.663	2.977	5.413	10.011	19.977	29.960	33.003
Right ascension (2000.0)	20h02.4m	14h38.7m	13h11.3m	21h14.2m	11h32.8m	16h37.9m	1h01.4m	22h36.1m	19h01.2m
Declination (2000.0)	–21°28'	–13°04'	–5°57'	–24°49'	4°12'	–20°27'	5°51'	–9°41'	–21°04'

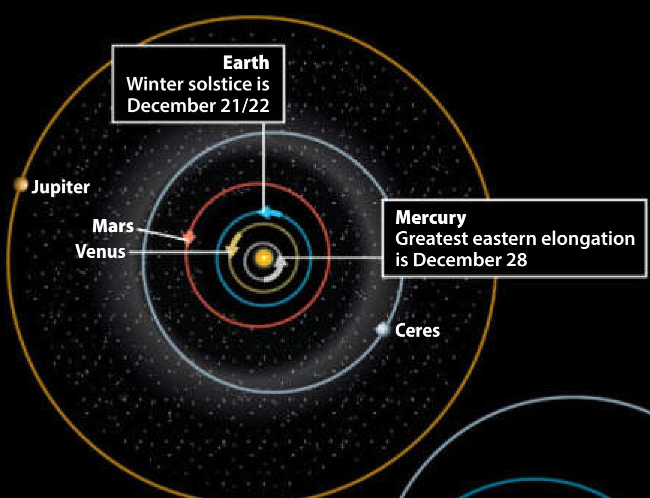
This map unfolds the entire night sky from sunset (at right) until sunrise (at left).
Arrows and colored dots show motions and locations of solar system objects during the month.

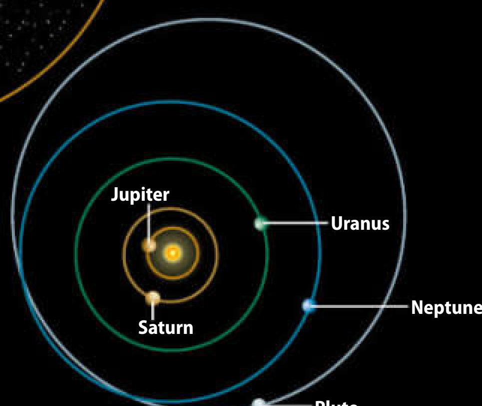
Astronomy magazine



Early evening

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.
Note: Moons vary in size due to the distance from Earth and are shown at 0h Universal Time.



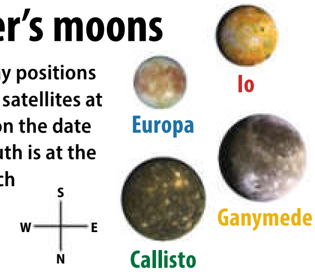


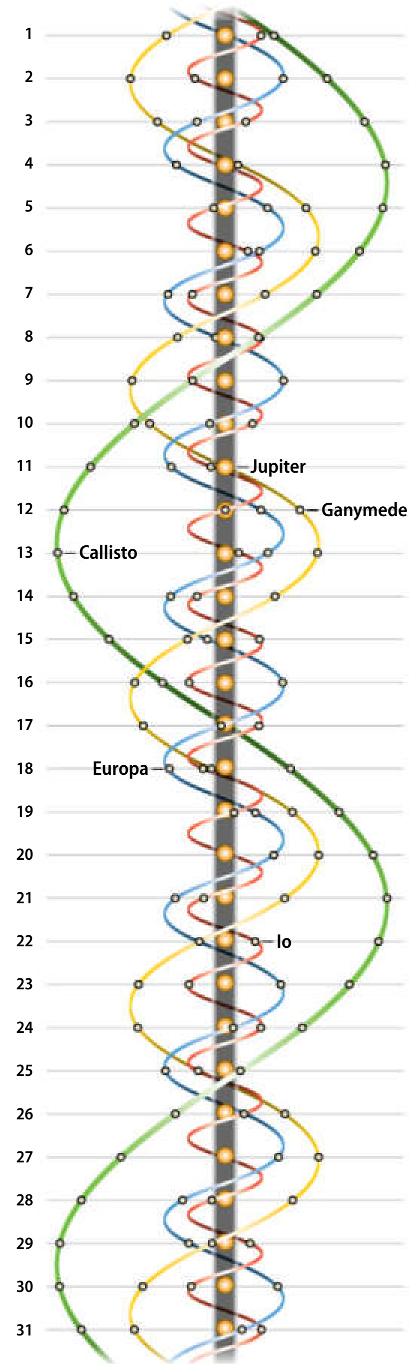
The planets in their orbits

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at mid-month from high above their orbits.

Jupiter's moons

Dots display positions of Galilean satellites at 5 A.M. EST on the date shown. South is at the top to match the view through a telescope.





ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

— *Continued from page 37*

WHEN TO VIEW THE PLANETS

EVENING SKY	MIDNIGHT	MORNING SKY
Mercury (southwest)	Jupiter (east)	Venus (southeast)
Uranus (southeast)	Uranus (west)	Mars (southeast)
Neptune (south)		Jupiter (south)
		Saturn (southeast)

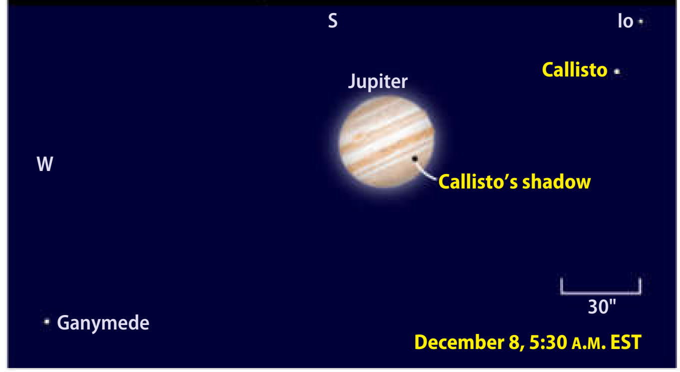
though even a little optical aid makes the task much simpler. Uranus moves glacially (appropriate for cold December nights) relative to the background stars in December, remaining 2° due south of magnitude 4.3 Epsilon (ε) Piscium. To quickly find its general location, run an imaginary line diagonally across the Great Square of Pegasus from its northwestern corner (Beta [β] Pegasi) to the southeast (Gamma [γ] Peg) and extend it an equivalent distance.

If you swing your telescope toward Uranus, you'll see a blue-green disk that spans 3.6". If you're observing the slightly gibbous Moon on December 19, slew your scope about 1.5° due north, and Uranus will come into view.

Just as Uranus sets in the west, the eastern sky lights up with the arrival of brilliant **Jupiter**. The giant planet rises around 12:30 A.M. local time in early December and more than an hour earlier by month's end. Jupiter brightens from magnitude –2.0 to –2.2 during December against the backdrop of much fainter stars in southeastern Leo.

Three hours after rising, Jupiter has reached an altitude of 30°. This provides three solid hours of observing time before twilight starts to paint the sky. The planet's disk spans a healthy 36" in early December and grows nearly 10 percent during the month as Earth's orbit brings the two worlds closer together.

Shadow play on Jupiter



On December 8, Callisto lies well east of Jupiter yet still manages to cast a shadow onto the gas giant's cloud tops.

This large size means you should get exquisite views of jovian cloud features. Most obvious are two relatively dark belts, one on either side of a bright zone that coincides with the planet's equator. The best views come during moments of steady seeing when the normally turbulent air flowing above your head (and telescope) calms for a few seconds. Take some time now to get familiar with Jupiter and the details visible in its massive atmosphere. This practice will prepare you to see the most when the world reaches opposition and peak visibility in March.

Any telescope also will show Jupiter's four bright moons. Io, Europa, Ganymede, and Callisto orbit above the planet's equator and thus wander east and west of the gas giant. When one of them passes in front of Jupiter, you can watch as its dark shadow

COMETSEARCH

Tails of dust and gas at dawn

With bated breath, observers across the Northern Hemisphere have been waiting for Comet Catalina (C/2013 US10) to pop into the predawn sky. If all goes according to plan, it could shine as bright as 4th magnitude in early December.

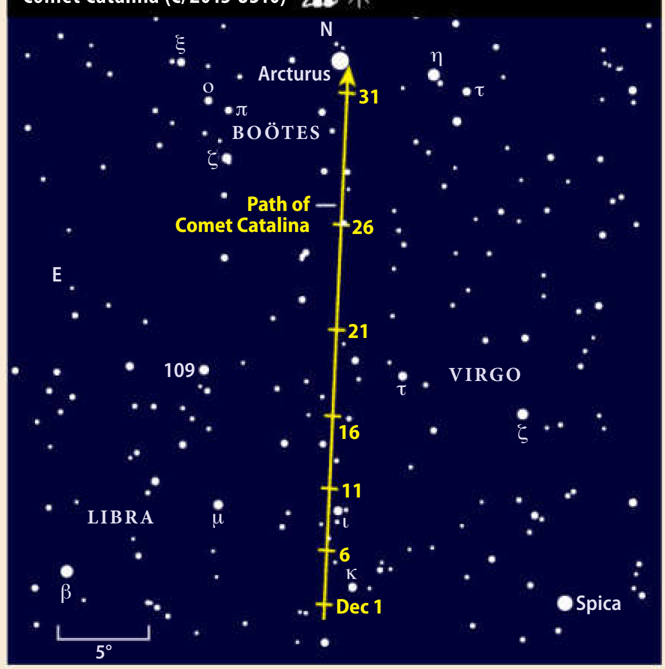
To many people, 4th magnitude hints at naked-eye visibility. Unfortunately, other considerations come into play. First, cities throw up a veil of light that will hide all but the central area. Second, magnitude predictions assume all the light is compressed into a star-like point. In reality, a comet's glow spreads out into a fuzzy ball and the average surface brightness is lower. Finally, the Moon spills its own light into the sky during early December.

But don't let that discourage you. The comet should be a pretty sight through binoculars or a telescope at low power. Imagers should be prepared the morning of the 7th to capture Catalina sharing an 8° field with Venus and a thin crescent Moon.

After the 8th, two weeks of Moon-free skies will let observers get detailed views of the comet's dust and gas tails. From our perspective, the two tails appear distinct. Although the comet's surface remains hidden by a veil of dust, the surrounding coma may show a greenish hue.

The Moon returns to the morning sky in late December as Catalina sets its sights on brilliant Arcturus. By then, the comet likely will have faded to 5th magnitude.

Comet Catalina (C/2013 US10)



If this visitor from the Oort Cloud matches expectations, it could hit 4th magnitude this month as it streaks north toward brilliant Arcturus.

Daytime drama for the Moon and Venus

ANTHONY AYIOMAMITIS

On June 18, 2007, Earth's satellite passed in front of Venus during daylight hours. North American observers can witness a similar event December 7.

and then its brighter disk cross the jovian cloud tops.

The angle of the Sun shining on Jupiter diverges noticeably from our line of sight during December. You can get a good idea of the difference December 8. Callisto's shadow falls on Jupiter's northern hemisphere starting at 4:17 A.M. EST when the moon itself is still 1.6' (nearly three Jupiter-widths) east of the planet.

Europa, the target of NASA's next major planetary mission, casts its shadow on Jupiter's cloud tops early on the mornings of Christmas Eve and New Year's Eve for observers in the Americas. On both days, Europa's shadow starts crossing the jovian disk about 2.5 hours before the moon itself.

The two planets that huddled with Jupiter in eastern Leo early last month string out across neighboring Virgo in early December. First to rise is **Mars**, which comes up nearly two hours after Jupiter. On the 1st, the Red Planet shines at magnitude 1.5 and stands 1.5° due south of magnitude 2.8 Gamma Virginis, the constellation's second-brightest star. Mars' orange hue contrasts nicely with blue-white Spica, Virgo's 1st-magnitude luminary, which lies some 14° southeast.

Mars tracks eastward during December and passes 4° north of Spica on the 21st.

The planet remains on the far side of the solar system from Earth and thus still looks tiny: a mere 5" across. At this size, only observers with large scopes can hope to pick up subtle surface details. Mars will grow much bigger, brighter, and more detail-rich next spring as it approaches opposition in late May.

Venus rises about an hour after Mars on December 1 and appears conspicuous in the eastern sky by 4 A.M. local time. At magnitude –4.2, it is five full magnitudes (a factor of 100) brighter than its companion Spica, which stands just 4° away. Venus moves quickly this month, crossing into Libra on the 11th. Look for the magnitude 2.8 double star Zubenelgenubi (Alpha [α] Librae) 2° south of Venus on the 17th.

The rapid changes to Venus' telescopic appearance this autumn slow considerably in December. The apparent size of its disk shrinks from 17" to 14" while its gibbous phase fattens from 67 to 77 percent lit.

If you're observing the morning of December 7, you'll no doubt notice the waning crescent Moon closing in on Venus. After sunrise, Luna passes directly in front of (occults) the planet for viewers across North America. You can follow this occultation through binoculars or a telescope.

The time when Venus disappears behind the Moon's sunlit limb depends on your location. The following are accurate to the nearest minute for several cities across the country: Seattle at 7:54 A.M. PST; Los Angeles at 8:04 A.M. PST; Denver at 9:36 A.M. MST; Houston at 11:12 A.M. CST; Chicago at 11:18 A.M. CST; New York at 12:42 P.M. EST; Boston at 12:43 P.M. EST; and Miami at 12:52 P.M. EST. If you want to view the event through a telescope, be sure to set up at least 30 minutes before these times.

LOCATING**ASTEROIDS**

An asteroid poses as a distant supernova

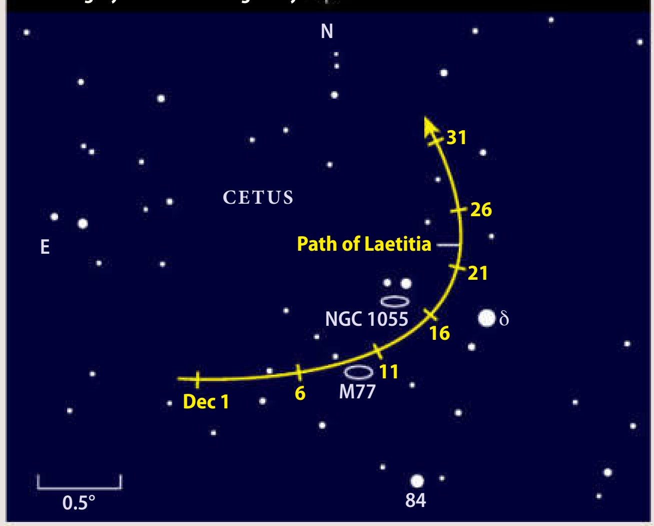
A small space rock could trigger some excitement among astroimagers when it passes close to the popular galaxy M77. On December 9 and 10, asteroid 39 Laetitia poses as a 10th-magnitude star on the fringe of this bright spiral, mimicking the light from a supernova nearly 50 million light-years away.

M77 is the founding member of Carl Seyfert's class of active galaxies. Hidden from view by gas, dust, and dense swarms of stars, the galaxy's core harbors a supermassive black hole busily devouring its surroundings.

You can pick up Laetitia and M77 with a 4-inch telescope from a dark site or an 8-inch instrument from the suburbs. The pair lies less than 1° east-southeast of 4th-magnitude Delta (δ) Ceti. Bump up the power past 100x, let yourself dark adapt a bit, and you should see three other faint fuzzies nearby, all part of the M77 group of galaxies.

To the eye, Laetitia will not move enough to notice during a single viewing session. When it's near M77 or between Delta and the spiral galaxy NGC 1055, make a quick sketch of the field and return to it the next clear night. The object that has shifted position is the asteroid.

Cruising by a whale of a galaxy



The 10th-magnitude asteroid Laetitia skirts north of the bright galaxy M77 in Cetus the Whale during the second week of December.

THE LOCAL GROUP

Our galactic neighborhood

The Milky Way's family of galaxies is locked in a multi-billion-year battle for gravitational supremacy.

by Katherine Kornei

The Milky Way's nearest cosmic neighbors, the Magellanic Clouds (right), reign in the southern sky, but our Local Group is home to many other small satellite galaxies. ESO/BABAK TAFRESHI

— *The Cosmic Distance Scale continued from page 35*

billion light-years

5.5 **5.75**

THE MILKY WAY GALAXY is like a hilltop village, according to astronomer Andrew Fox. "At nighttime you can see torches shining in two nearby villages, the Magellanic Clouds, and a more distant one, Andromeda," he says. "For a long time, those were the only other villages known. Then, one day, someone put two lenses together to make a telescope, looked round, and saw many tiny villages scattered around the surrounding hills and realized that the maps had to be redrawn. That's the Local Group — it's where we live."

For most of human history, it was inconceivable that anything existed beyond the Milky Way. After all, the Milky Way is our home galaxy, and its billions of stars provided enough of a nighttime show to fascinate stargazers for millennia. Even now, in the era of space-based telescopes and sensitive cameras, backyard and professional astronomers alike can easily devote lifetimes to studying the Milky Way and its planets, stars, and nebulae.

But a peek over the celestial fence beyond the Milky Way's tenuous halo yields a rich view of the nearby universe and galaxy evolution in progress.

The approximately 85 gravitationally bound galaxies near the Milky Way are collectively known as the Local Group. This population of galaxies, spread over roughly 10 million light-years, encompasses not only the Milky Way and several bright galaxies visible to the naked eye, but also many much smaller galaxies that dominate the Local Group by number. By studying the Local Group, astronomers can observe galaxies in their entirety, no longer confined to understanding a galaxy from the inside out.

Follow the stream

Astronomers on Earth have front-row seats to the show of galaxy formation in the Local Group. Comparatively puny galaxies often collide with more massive galaxies, their meager stockpiles of gas and dust being absorbed into the larger system of stars. Dwarf irregular galaxies, as their name suggests, are low in mass and lack geometrical structure. They're visually unimpressive and resemble jumbles of stars — blink and you'll miss them — with not a spiral arm in sight. Dwarf irregular galaxies in the Local Group can have just a few thousand stars, which makes them downright pint-sized compared with the Milky Way and its hundreds of billions of stars. Even so, astronomers are keen to better understand these featherweights of the cosmos.

"By studying the extremes of any population, we learn more about the population as a whole," explains Marla Geha, an astronomer at Yale University whose research focuses on the origin and evolution of dwarf galaxies.

The largest and best-known dwarf irregular galaxies in the Local Group are the Large and Small Magellanic Clouds, which look like fuzzy patches in the Southern Hemisphere night sky. The Magellanic Clouds feature prominently in myths: Aboriginal people in Australia tell stories of the Magellanic Clouds alternatively as a man and a woman, hunters, or the ashes of rainbow lorikeets (birds). The Large and Small Magellanic Clouds lie some 160,000 and 200,000 light-years away, respectively, distances slightly greater than the diameter of the Milky Way. Given their relative proximity, each Magellanic Cloud holds the distinction of

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NASA/ESA/J. DALCANTON, B.F. WILLIAMS, AND L.C. JOHNSON (UNIV. OF WASHINGTON)/THE PHAT TEAM/R. GENDLER

To celebrate the Hubble Space Telescope's 25th birthday, astronomers created the instrument's largest image yet thanks to more than 7,000 exposures. This panorama of the Andromeda Galaxy 2.5 million light-years away stretches from our neighbor's dense central bulge to its sparse outer disk.

being one of a smattering of galaxies in which scientists can resolve individual stars.

"Studying the motion and composition of individual stars allows us to build a much more accurate and detailed picture of how a galaxy formed as opposed to studying the combined light from many stars," Geha says.

Hubble Space Telescope images have revealed that the Large Magellanic Cloud is forming stars in dense groups that may be the precursors to globular clusters. Some stars in these groups are thought to weigh as much as 100 Suns; they're prodigiously bright and emit winds that sculpt nearby gas into bubbles and streamers. These intense star formation sites allow a better understanding of high-mass-star formation, a process common in galaxies that are much farther away than the Local Group.

The Large and Small Magellanic Clouds are gravitationally bound to the Milky Way, but astronomers have yet to agree whether the galaxies have completed several Milky Way orbits or if they're plunging into our galaxy's halo for the first time.

"I'd say the jury is still out, chiefly because we don't know the total mass of the Milky Way very well," says Fox, the Space Telescope Science Institute astronomer who likened the Milky Way to a hilltop village. "This uncertainty means the Milky Way's gravity is also not precisely known, which directly affects the orbits of the Magellanic Clouds."

Regardless of how many times the Magellanic Clouds have orbited the Milky Way, one fact remains certain: The Milky Way's gravity is ripping both apart. Fox and his colleagues have shown that the Milky Way is stripping away the gas of the two dwarf galaxies and collecting it in a massive cloud known as the Magellanic Stream. This cloud stretches across one quarter of Earth's sky. Because gas is necessary to form stars, the Milky Way is collecting star-forming material and depriving the Magellanic Clouds of their stellar fuel.

"There has been a lot of attention in recent years about how much gas there is around galaxies and how that gas enters those galaxies to feed star formation," says Fox. Observations of the Magellanic Stream afford astronomers a close-up view of gas cycling between galaxies, demonstrating that larger galaxies can act like cannibals and literally consume their smaller companions.

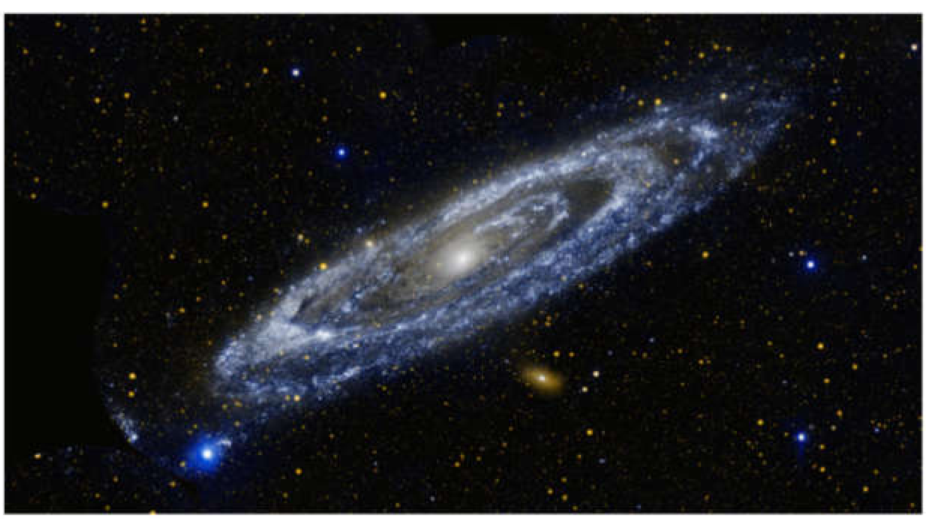
Missing metals and mass

Stars are factories for making metals, which astronomers consider to be any element heavier than helium. Some of the metals that stars produce become part of the nebulae from which later generations of stars are born. Therefore, the prevalence of metals in a galaxy — its metallicity — increases over time, at least for galaxies that are actively forming stars. Larger galaxies contain a higher fraction of metals, on average, than smaller ones.

The most massive galaxies in the Local Group — the Milky Way and Andromeda (M31) — contain the highest fractions of metals, which explains the rings on your fingers, your cellphone, and the spoon you used to stir this morning's coffee.

The dwarf irregular galaxies in the Local Group have metallicities that are much lower. Astronomers refer to low-metallicity galaxies as being "chemically pristine" — they are composed almost entirely of hydrogen and helium, just like

GALEX/NASA/JPL-CALTECH



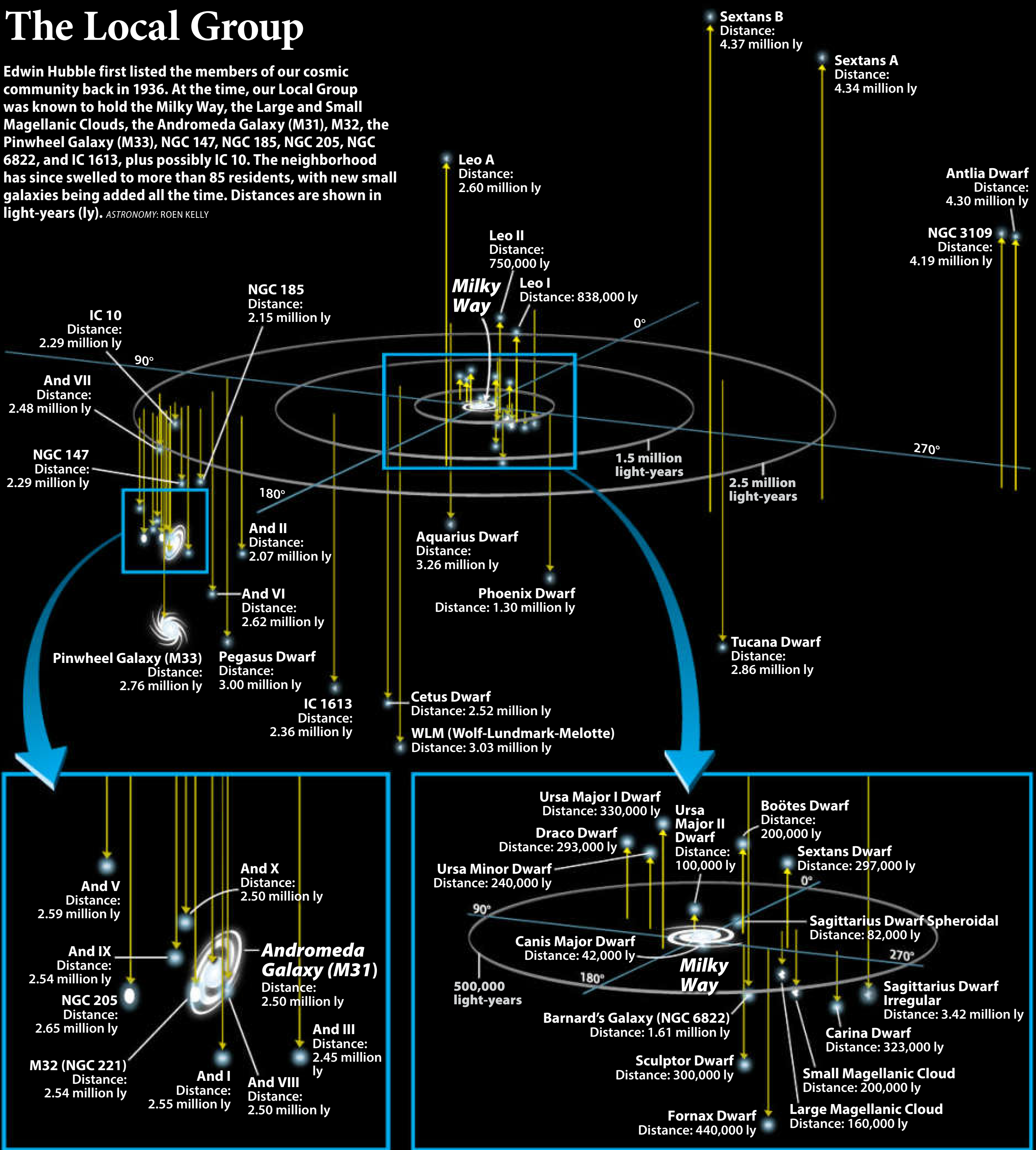
The Andromeda Galaxy (M31), seen here in ultraviolet light, is the largest galaxy in the Local Group with some 1 trillion stars — roughly twice the population of our own Milky Way.

billion light-years

6.5 6.75

The Local Group

Edwin Hubble first listed the members of our cosmic community back in 1936. At the time, our Local Group was known to hold the Milky Way, the Large and Small Magellanic Clouds, the Andromeda Galaxy (M31), M32, the Pinwheel Galaxy (M33), NGC 147, NGC 185, NGC 205, NGC 6822, and IC 1613, plus possibly IC 10. The neighborhood has since swelled to more than 85 residents, with new small galaxies being added all the time. Distances are shown in light-years (ly). *ASTRONOMY:* ROEN KELLY



ESO/SOAR (EL GORDO CLUSTER)

El Gordo Cluster
7.25 billion light-years

7

7.25

Andromeda and the Milky Way dominate the Local Group of galaxies, but the Pinwheel (M33) packs a still respectable 40 billion stars, making it the third largest in the neighborhood. It's also often considered the most distant object visible with the naked eye. ESO

The Large Magellanic Cloud is close enough for astronomers to resolve individual stars within it, making this dwarf irregular galaxy a rare laboratory to study how galaxies form. NASA/JPL-CALTECH/M. MEIXNER (STScI) & THE SAGE LEGACY TEAM

the universe shortly after the Big Bang. These systems are like time capsules: They let astronomers study what the early universe looked like before stars "polluted" space with metals.

Researchers discovered one such chemically pristine galaxy in the Local Group using data collected by the Sloan Extension for Galactic Understanding and Exploration (SEGUE), a comprehensive survey of the sky conducted between 2004 and 2008. Astronomers combed through SEGUE data to search for stars that had both similar positions and velocities, hoping to find new galaxies that were much too small and faint to see with current telescopes. In 2009, scientists in the United States and Europe discovered a tiny galaxy in the SEGUE data. The galaxy, which they named Segue 2, orbits the Milky Way but is only 1/500 its size.

Since Segue 2 is relatively nearby — 114,000 light-years away, less than the diameter of the Milky Way — astronomers are able to study the prevalence of metals in its resolved stars. In astronomy, as in sports and politics, studying individuals as opposed to relying on population averages often leads to new insights. Researchers at the University of Michigan and the University of California, Irvine, used the 6.5-meter Magellan Telescope in Chile to study the metallicity of Segue 2's brightest star, a red giant. They found that the star had a surprisingly low metallicity: only 0.1 percent that of the Sun. These measurements suggest that Segue 2 has not experienced much star formation, which other observations confirm.

"Right now, Segue 2 has a few thousand stars, and it took a few hundred million years to form them," says Evan Kirby, an astronomer at the California Institute of Technology who studies Segue 2. "So that's an average star formation rate of 0.00001 stars per year, which is pathetic."

Segue 2 is peculiar in another respect: its mass (or lack thereof). Most galaxies contain copious amounts of dark matter, a mysterious substance that interacts gravitationally with other matter but does not emit, reflect, or scatter light. Typical galaxies like the Milky Way have 10 times as much dark matter as normal matter. Less massive dwarf galaxies have relatively more dark matter, up to 1,000 times as much as normal matter. When Kirby and his team first looked at Segue 2, they expected it to also have lots of dark matter. They studied how its stars moved using the Keck II Telescope in Hawaii and inferred that the ratio of dark matter to normal matter in Segue 2 was at most 300 to 1 — far less than predicted.

"The small ratio potentially indicates that the Milky Way has stripped off some of Segue 2's dark matter," Kirby says. The observations revealed that the total mass of Segue 2 — including dark matter — was a puny 200,000 times that of the Sun. That may sound like a lot of mass, but it's actually 10 million times less massive than the Milky Way.

Segue 2 is a ladybug to the Milky Way's Volkswagen Beetle.

"These systems have all the properties of galaxies but ridiculously few stars. That a galaxy this puny can form at all is a surprise to me," Geha says.

And it might not be alone. Astronomers suspect that the Local Group could harbor far more galaxies than the roughly 85 that are currently known. "For every galaxy that we see, there could be a couple hundred that we don't see," Kirby says. "To be fair, most of these unseen 'galaxies' may not have any stars — just dark matter — which makes it questionable to call them galaxies."

Searches are underway to find such dark-matter-dominated galaxies, and earlier this year a team of astronomers led by Sukanya Chakrabarti at the Rochester Institute of Technology announced four stars possibly belonging to a Local Group galaxy consisting mostly of dark matter.

Toward the Princess

The Milky Way's gravitational entourage — the Magellanic Clouds, Segue 2, and other nearby dwarf irregular galaxies — isn't unique in the Local Group. The Andromeda Galaxy, some 2.5 million light-years away, has several orbiting satellite galaxies as well. This fact shouldn't come as a surprise since the Milky Way and M31 are the largest galaxies in the Local Group.

"As one of the two most massive members of the Local Group, Andromeda drives

much of the evolution of the group," explains Benjamin Williams, an astronomer at the University of Washington who studies stellar populations within nearby galaxies. In fact, M31 shows evidence for even more interactions with its cadre of gravitational groupies than the Milky Way. "It has a more structured stellar halo that is full of streams, indicative of a more violent past," Williams says. "Its satellite galaxies have much less current star formation, also suggestive of more interactions."

Earlier this year, astronomers at the University of Notre Dame and the University of Wisconsin-Madison published the discovery of a massive halo of gas around M31. The halo, which they discovered using Hubble, extends halfway to the Milky Way and contains metals such as carbon, oxygen, and silicon, some of which may have been stripped from satellite galaxies that merged with Andromeda.

Demonstrating that large galaxies consume smaller galaxies is more than just a morbid pursuit, however. "Observing a dwarf galaxy getting stretched out until it disrupts into the smooth outskirts of the Milky Way or Andromeda is to see galaxy growth in action," Kirby says. Astronomers like Kirby want to understand how galaxies assemble over time into the ones we observe today without having to wait the roughly 5 billion years before the Milky Way and Andromeda collide.

"That collision will erase the spiral arms of the Milky Way and Andromeda, and we will be left with one mostly featureless elliptical galaxy," Kirby says. But the dwarf irregular galaxies in the Local Group aren't destined for such drastic collisions. "Most of the dwarf irregulars will continue orbiting their larger hosts — even after the big collision — and their stellar populations will remain unchanged."

When the Milky Way and Andromeda do finally collide, the supermassive black hole at the center of each galaxy will orbit around each other, releasing copious amounts of energy. Supermassive black holes are relatively rare in the Local Group, however: Out of the roughly 85 galaxies, only three — the Milky Way, Andromeda, and a dwarf elliptical satellite of Andromeda known as M32 — show evidence for such a monster. It's no coincidence that these three galaxies are also among the most massive systems in the Local Group. "The smallest galaxies with known central black holes typically have stellar masses of about 1 billion solar masses," explains Kirby. "Most of the dwarf irregulars in the Local Group top out at 100 million solar masses, so there is not yet any evidence for supermassive black holes in these galaxies."

Cosmic cannibalism appears to be ubiquitous around large galaxies in the Local Group. Even so, some galaxies seem to be remarkably immune to it. The spiral galaxy M33, also known as the Pinwheel Galaxy, is the third-largest galaxy in the Local Group after the Milky Way and M31. It orbits Andromeda yet possesses no central bulge of stars, which is often a telltale sign of previous galactic mergers. Furthermore, its 40 billion stars are arranged in a spiral, a fragile geometry that would have been destroyed by any significant gravitational interactions.

NGC 604, an enormous star-forming region in M33, is evidence that the galaxy contains copious amounts of gas. If the Pinwheel's gas reservoirs were somehow stripped away by Andromeda at some point in the past, the gas must have been replenished before NGC 604's first stars began to form several million years ago.

"M33 gives us a nearby subject for learning about disk formation and evolution in a galaxy that experiences little harassment from satellites," Williams says.

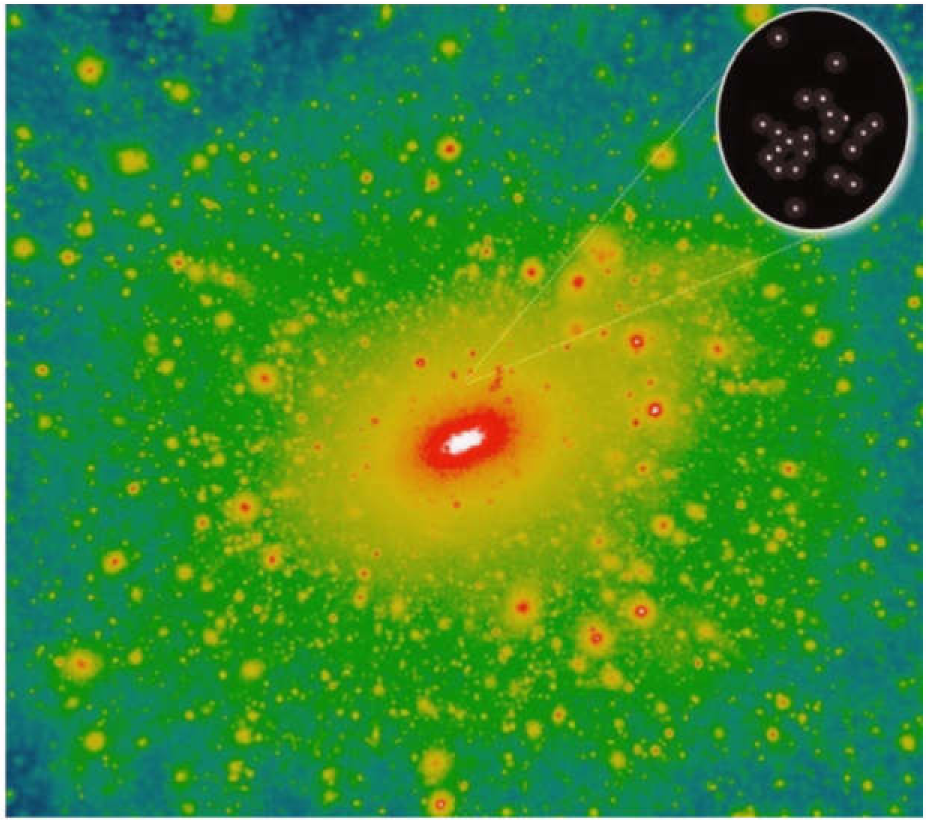
Far away from the Milky Way and Andromeda, the Local Group's remaining galaxies exist in relative solitude. They're the last torches before reaching other distant galaxy clusters, which themselves are part of the larger Virgo Supercluster. Astronomers can now study galaxies in our home supercluster in intricate detail using advanced telescopes and cameras, but the hilltop villages of the Local Group still beckon like beacons.

FAST FACT

1,000,000

LIGHT-YEARS

Reach of the Andromeda Galaxy's dark matter halo, which extends halfway to the Milky Way.



Tiny galaxy Segue 2 is one of the strangest neighbors on our cosmic block. Dwarf galaxies typically have many times more dark matter than normal matter, but this one has relatively little — an indication the Milky Way has stripped much of the dark matter away. GARRISON-KIMMEL, BULLOCK (UCI)

Our 100,000 closest galaxies

Small groups combine with larger clusters to form a vast network of interconnected galaxies that spans 110 million light-years.

by Sarah Scoles

The Milky Way sits near the middle of an assembly of galaxies called the Local Group. This gathering, 10 million light-years wide, lives on the edge of a collection of galaxy clumps called the Local, or Virgo, Supercluster.

British astronomers and father-son duo William and John Herschel pointed their telescopes all over the sky in the 18th and 19th centuries, taking samples of objects they called "nebulae." In using the word *nebula*, they didn't always mean what we do today. They merely meant a celestial object that wasn't a comet but nonetheless appeared fuzzy. And they believed all these nebulae lay within the Milky Way.

In their 1864 catalog, John noted that more nebulae populated the area around the constellation Virgo. (French astronomer Charles Messier also had noted such structure a century earlier.) The reason, though, remained nebulous.

In 1920, the "Great Debate" attempted to resolve the nature of nebulae. American astronomers Harlow Shapley and Heber Curtis argued about whether these objects represented nearby cloudiness or whether they were galaxies in their own right, rendered fuzzy by distance. The latter interpretation won out. But why did these galaxies cluster around Virgo? Was it chance or something more?

In the 1950s, French astronomer Gérard de Vaucouleurs observed how these Virgo galaxies traveled through space. Curiously, they seemed to be moving away from us at the same speed and lay fairly close to one another and to us. They were, in astronomy parlance, "dynamically related." In 1953, he christened this crowd the Local Supergalaxy. Five years later, he changed it to the Local Supercluster.

As telescopes became more powerful, astronomers could take larger surveys, cataloging more galaxies and their motions. These pixeled together a bigger picture: a concentration of galaxies along a plane in space. Just as most of the Milky Way's stars reside in a thin equatorial disk, so most of the galaxies in the Local Supercluster lie along its equator. Science had spoken — stars cluster in galaxies, galaxies cluster in clusters, and clusters cluster in superclusters. And the center of our supercluster shared a spot in the sky with Virgo.

If you placed 1,000 Milky Ways end to end, they would span 100 million light-years — the size of our supercluster. Two-thirds of the bright galaxies live in a disk near the equator, around which the remaining third spread like the globular clusters around our galaxy. In total, a mass equivalent to 10 quintillion Suns fills our cosmic supercity. Much of that mass, however, isn't luminous. Just as dark matter dominates the universe, it also fills the supercluster. Still, lots of pretty light-emitting objects live next door, cosmically speaking.

Meet the neighbors

Closest to us, perhaps 11 million light-years away, live the Maffei I and II groups. Although nearby, they went unnoticed until 1968 because they lie right behind the Milky Way's plane, so the material that makes up our home drowns out the light from Maffei's constituents. But Italian astronomer Paolo Maffei noticed something strange when he looked at IC 1805 (a true nebula). A nearby object shone in infrared light. He guessed it was a galaxy, obscured by the Milky Way. In the past 20 years, astronomers have found 17 more associated galaxies.

A million light-years farther away, the Sculptor Galaxy Group is easier to pick out. From 2011 to 2013, a group of astronomers led by Tobias Westmeier of the International Centre for Radio Astronomy Research in Australia studied how high-velocity clouds (HVCs) of hydrogen enrich member galaxies NGC 55 and NGC 300. HVCs don't rotate with galaxies; instead, they come from outside and stream in like missiles. Astronomers believe they may provide fuel to produce more stars as galaxies run out of their own gas. But HVCs have to come from somewhere.

At the time of Westmeier's study, two theories dominated, and he wanted to find which was true. In one, HVCs are clumps of gas shot out of a galaxy by supernovae; in the other, they are dwarf galaxies

Former Astronomy *Associate Editor* **Sarah Scoles** *is a freelance writer currently living in the San Francisco area.*

The Southern Pinwheel Galaxy (M83) is the second-brightest member of the Centaurus A Group. At a distance of some 15 million light-years, it lies some 3 million light-years beyond the group's brightest member, Centaurus A. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

8.75 9

Galaxies Maffei I and Maffei II are the centers of the two closest galaxy groups. This infrared image penetrates material in our galaxy that hides the two in visible light. NASA/JPL-CALTECH/WISE TEAM

NGC 300 resides on the near side of the Sculptor Galaxy Group, whose bulk lies 12 million light-years from Earth. The galaxy appears nearly as big on the sky as the Full Moon. ESO

dominated by dark matter and gas that never formed stars. "Due to its proximity, the Sculptor Group was the most obvious choice for this study," he says, "enabling observations at sufficient resolution and sensitivity to detect potential HVCs."

They found the population they expected around NGC 55 but none around NGC 300. This discovery automatically knocked out the idea of dark satellite galaxies because both objects, being around the same size, should have formed a similar set of satellites. The lack of clouds, then, suggested that HVCs come from gas flowing into or out of the main galaxy, which happens when bigger galaxies eat smaller ones or when stars form.

The big surprise from the study, however, was about wonkiness in the big galaxies' gaseous disks. They appear to wobble as they travel through space under the influence of a force called ram pressure. This could happen only if the galaxy slammed into a dense intergalactic medium. While astronomers know that large clusters bathe in dense soups of material, they thought smaller groups sat in thin broths.

The pressure blows gas away, meaning stars can't form as well — or at all in the case of small satellites. "As gas constitutes the fuel for future star formation, its removal could potentially shut down star-formation activity in dwarf galaxies living in group environments," says Westmeier.

This discovery helps solve a mystery called the "missing satellites problem," which arose about 15 years ago when computer simulations showed that galaxies like the Milky Way should have more dark dwarf-sized companions than they do. "This discrepancy suggests that either there is something wrong with the simulations or some mechanism has prevented the majority of dark matter halos from turning into proper galaxies," says Westmeier. If pressure strips gas away, as it seems to in the Sculptor Group, small galaxies wouldn't be able to form stars, meaning the satellites aren't missing — they're invisible.

The unusual suspects

The Centaurus A Group lies at a similar distance as Sculptor, some 12 million light-years from Earth. The group's dominant member, Centaurus A, is the closest radio galaxy. This massive object swallowed a spiral galaxy about 500 million years ago. The digestion is ongoing, though, and it causes radio waves to blast into space. Centaurus A serves as an example of what could ensue when the Milky Way and Andromeda galaxies collide 4 billion years from now.

A more visually recognizable crowd — the M81 Group — resides at the same distance. Located inside the boundaries of Ursa Major and Camelopardalis, it contains 1 trillion solar masses and 34 known galaxies, the most famous of which are M81 and M82. The two tug on each other, which has turned M82 into a star factory. The galaxy's center glows 100 times brighter than the Milky Way's as hydrogen gas falls from intergalactic space toward the gravitational hub.

The galaxy causing some of this ruckus, M81, holds the title of "Biggest Galaxy in its Group." At the center of its perfect spiral arms lurks a supermassive black hole weighing 70 million solar masses.

Chaotic concentrations

In contrast to the order in the M81 Group, the Canes Venatici I Group seems chaotic. Located 15 million light-years away in the constellations Canes Venatici and Coma Berenices, this group's members are bound only loosely to one another. Not all of its approximately 20 galaxies have settled into stable orbits, and they seem to be just weakly connected gravitationally.

Several million light-years farther out and back in the direction of Ursa Major, the M101 Group has the same loose, disconnected air. This group's namesake keeps the family together. Most of the other galaxies in the group are merely companions of this Milky Way twin. M101 spans 170,000 light-years, has tightly wound spiral arms, and holds 100 billion solar masses' worth of material.

Less than 20° to the southwest, we find the Canes Venatici II Group. Thirty

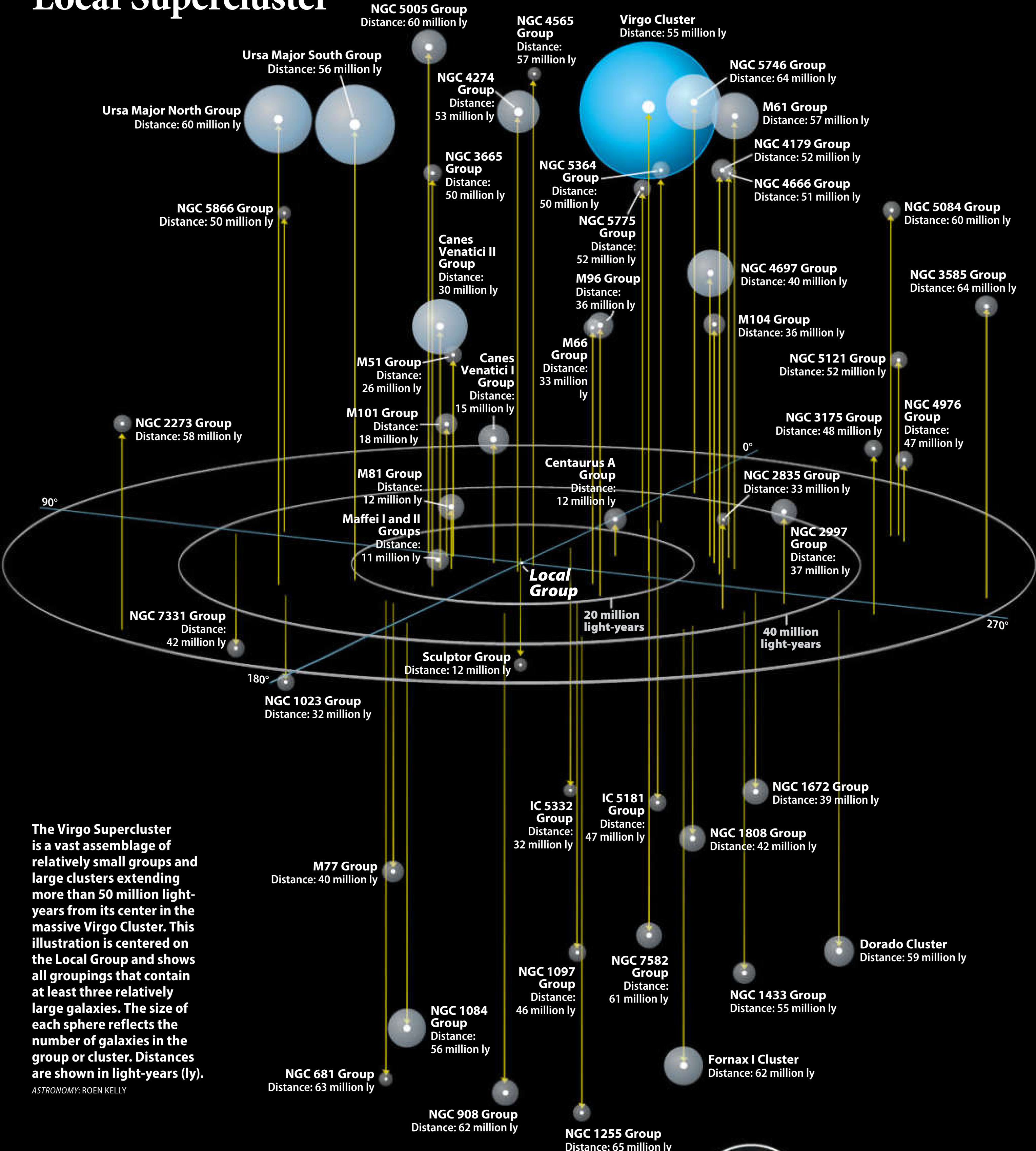
Centaurus A dominates its group from a distance of 12 million light-years. The massive galaxy shines brightly in both visible light and radio waves, the latter a result if its having consumed a companion galaxy 500 million years ago. ESO

Twin Quasar (Q 0957+561)
9.18 billion light-years

billion light-years
9.25
9.5

NASA/ESA/HUBBLE (TWIN QUASAR, EINSTEIN'S CROSS)

Local Supercluster



The Virgo Supercluster is a vast assemblage of relatively small groups and large clusters extending more than 50 million light-years from its center in the massive Virgo Cluster. This illustration is centered on the Local Group and shows all groupings that contain at least three relatively large galaxies. The size of each sphere reflects the number of galaxies in the group or cluster. Distances are shown in light-years (ly).

ASTRONOMY: ROEN KELLY

Einstein's Cross
9.85 billion light-years

9.75

10

Galaxy M82 resides in a large group named for its neighbor, M81. An ongoing interaction between these two has sparked M82 to produce vast numbers of new stars. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Spiral galaxy M101 is the dominant member of its galaxy group, which lies 18 million light-years from Earth. The 170,000-light-year-wide island universe appears face-on from our perspective. NASA/ESA/K. KUNTZ (JHU), ET AL./STScI

million light-years from home, this group's largest and most famous member is M106. Water vapor in this galaxy pulses out microwave radiation, creating a giant microwave equivalent of a laser called a megamaser. Astronomers used the water megamasers orbiting M106's supermassive black hole to directly measure its distance.

The galaxy also contains visible Cepheid variable stars, "standard candles" whose predictable brightness changes astronomers also can use to tabulate distance. These stars dim and brighten periodically like seizure-inducing Christmas lights, and the period gives away the star's intrinsic luminosity. By comparing this to the star's observed brightness, astronomers can calculate how far away it is. Thus, the water megamasers and Cepheid variables in M106 help scientists calibrate the cosmic distance scale.

One ring rules them all

The M96 Group in Leo lies some 36 million light-years away and has a number of big, bright galaxies — 12 with diameters above 30,000 light-years. In 2010, it also helped astronomers investigate how galaxies form thanks to a ring of chilly gas 650,000 light-years wide that encircles the group. For 30 years, no one understood where it came from or what exactly it was.

Then a team led by astronomers at Lyon Observatory decided to tease out the ring's nature. The researchers believed that it might reveal itself to be "primordial gas," gas that has never lived inside another galaxy and can't, in its current form, transform into stars. For galaxies to form, astronomers think cold primordial gas has to fall into the system, like high-nutrition food to help fuel the growth of early years. But no telescope had seen such old-school atoms around a growing galaxy. The Leo Ring, these scientists thought, might be just that.

But when they turned their telescope on it, they found bright optical light, the kind that massive young stars emit. Primordial gas, by definition, cannot create such stars. They had a new mystery.

Using computer simulations, the team discovered that the ring represents a scar left over from a colossal collision: NGC 3384, a central elliptical galaxy, and M96, a peripheral spiral, smashed into each other more than a billion years ago. The gas from one blew away, eventually forming the ring.

The biggest and baddest

The Virgo Cluster, the most significant collection of galaxies with the home address

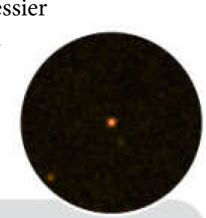
Microwaves from water vapor in M106 helped pin down its 30-million-light-year distance. NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)/R. GENDLER (FOR HUBBLE HERITAGE TEAM)

"Local Supercluster," has a center some 55 million light-years away. As its name suggests, you can find it in the direction of the constellation Virgo. Compared to the meager dozens of galaxies in the previous groups and clusters, Virgo has 1,300 — and maybe even 2,000 — constituents. They add up to 1.2 quadrillion solar masses spread across 7.2 million light-years.

In between these galaxies roams a rogue set of intergalactic stars — up to 10 percent of the cluster's total. Globular clusters, dwarf galaxies ripped from parents, and at least one star-forming region also populate the intergalactic region. Hot X-ray-emitting gas permeates the space where these orphans live.

The Virgo Cluster is so big that it actually has subclumps: Virgo A, Virgo B, and Virgo C. Virgo A dominates, encompassing 10 times as much mass as the other two. The three eventually will merge into a single giant cluster. Because these subgroups have yet to coalesce, astronomers suspect Virgo is young and still figuring out its identity.

At the cluster's center — and the center of subgroup Virgo A — lies the giant elliptical galaxy M87. Bright galaxies like M87 fill the Virgo Cluster. They are, in fact, the concentration that Messier and the Herschels noticed — the first evidence that superclusters exist. Fifteen of Messier's objects are found in this congregation. And you can see



3C 9 (quasar)
10.44 billion light-years

DSS2 (3C 9); NASA/ESA/R. GOBAT, ET AL. (CL J1449+0856)

billion light-years

10.25

10.5

many of its members — including M84, M86, M87, and the Sombrero (M104) and Black Eye (M64) galaxies — through modest backyard telescopes.

Because Virgo has so many galaxies at approximately the same distance from Earth, astronomers use the cluster as a laboratory to study galaxy evolution. Just as an alien visitor would learn more about human development by looking at a stadium full of different people than at a single family, so too can astronomers learn more about galaxies from a huge batch like the one in Virgo.

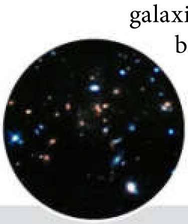
One thing they learned recently deals with star formation — more specifically, stars that are not forming as fast as many expected. A 2014 study found that turbulence — the kind that shakes airplanes — in the center of Virgo shakes up star-making gas, keeping it hot for billions of years. That turbulence, which comes from active black holes in galaxy centers shooting out powerful jets, prevents the gas from becoming stable enough to form stars.

"The energy in such slow motions is more than enough to stop gas from catastrophic cooling and star formation," says lead researcher Irina Zhuravleva of Stanford University in Palo Alto, California. Understanding why stars stop forming at the centers of galaxies and clusters helps astronomers understand how their lives progress and how the life of our own galaxy and group might unfold.

Fish and bears

Even farther out, a 59-million-light-year jaunt, lies the Dorado Group. This large collection comprises 70 galaxies in the direction of the southern constellation Dorado the Dolphinfish (a species that appears on menus as "mahi-mahi"). One of its most prominent members, NGC 1483, shows a luminous central bulge and jumbled spiral arms that host bright star-forming regions and young star clusters.

At approximately the same distance but in the direction of Ursa Major, two groups form a defined band. Most of its major galaxies are spirals, and these combine with the minor ones to produce 30 percent as much light as the Virgo Cluster. Thirty percent may not sound impressive, but consider

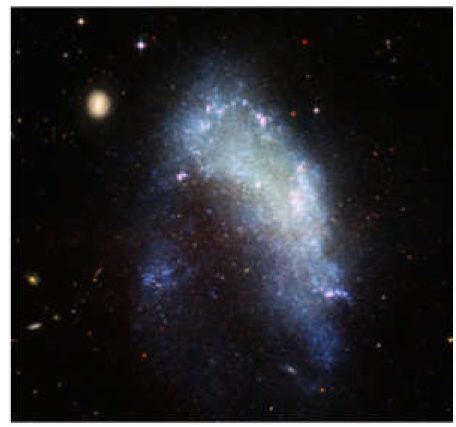


CL J1449+0856 (farthest galaxy cluster)
10.51 billion light-years

The giant Virgo Cluster contains more than a thousand galaxies. The central region seen here includes the cluster's most massive member, M87, below center. TERRY HANCOCK

that the Ursa Major groups contain just 5 percent of Virgo's mass.

Thirty-two galaxies call the Ursa Major North Group home, including the bright spirals NGC 3631, NGC 4088, NGC 3953, and M109. The last of these looks most similar to the Milky Way. Of all 109 objects in the Messier catalog, it lies farthest away, meaning that 18th-century telescopes couldn't decipher things beyond this point. Now, however, large scopes on Earth and in space give us glimpses of galaxies billions of light-years more distant.



NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA)

At 62 million light-years, the Fornax I Galaxy Group (and NGC 1427A, seen here) is one of the Local Supercluster's most distant members.

Moving targets

But classifying those galaxies into categories has always been a problem. They orient themselves differently relative to us, and a face-on spiral looks quite different from one seen edge-on. We only have a 2-D sense of galaxies, as if they're projected on a screen, rather than a true 3-D picture. The problem is particularly acute for disk-shaped galaxies, such as spirals, and spheroidals. You can tell the difference, though, by watching how their stars move. If they rotate slowly and disorderly, they're spheroidal. If they rotate fast and in an orderly manner, they are disk galaxies.

A team of astronomers led by Nicholas Scott of the University of Sydney in Australia set about to study the stellar motions in the Fornax I Cluster, 62 million light-years away. They found that 93 percent of the cluster's galaxies were fast rotators (spirals) and just 7 percent were slow rotators (spheroidals). Combining this study with those of other clusters, including the larger one in Virgo, Scott's team found that the spheroidals tended to hover near a cluster's center — either because they began there or migrated there.

"One of the long-debated ideas is the question of nature versus nurture in galaxy evolution," says Scott. Is how a galaxy looks today totally determined by its properties in the early universe, or do its surroundings play a role too? "This study shows that, for at least some galaxies, the environment does play a major role." He adds that many questions still exist, which further cluster studies can answer.

More questions always exist about the cosmos — its stars, galaxies, groups, clusters, superclusters, and beyond. And because the universe is organized into superclusters, their constituents stay "close" together. Astronomers can swing their telescopes and find a stadium alive with variety. They learn not just what the more distant universe is like, but also what it used to be like, what it will be like, and what has happened and will happen even closer to home.

10.75

LIMITS OF THE COSMOS

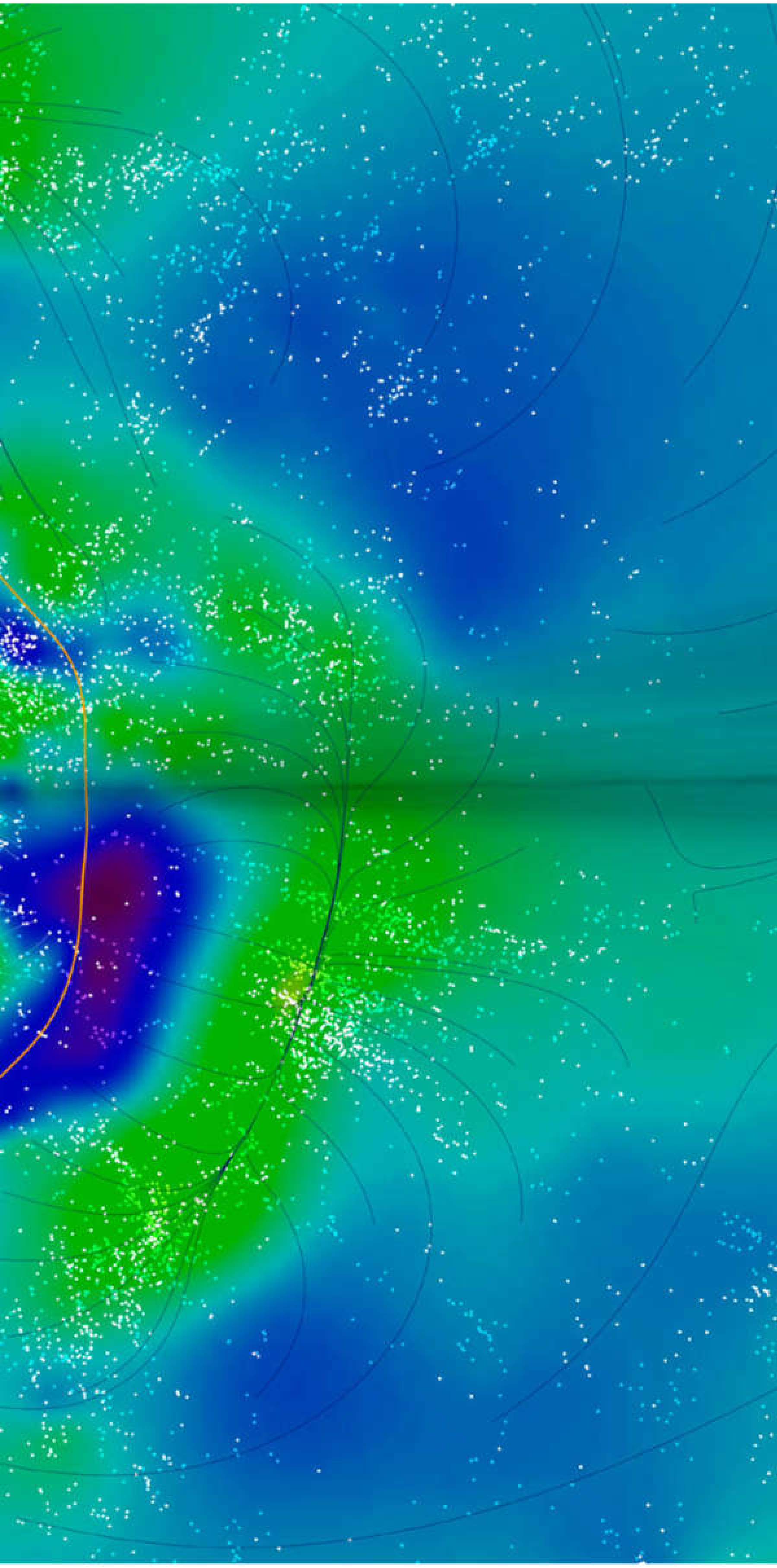
The far reaches of space

Using the relative velocities of galaxies, astronomers in September 2014 defined the Laniakea Supercluster (the region within the outline) as the one that contains the Milky Way, the Virgo Supercluster, and several others. Laniakea contains more than 100,000 galaxies with a combined mass of 10^{17} Suns in a region of space 520 million light-years across.
R. BRENT TULLY, HELENE COURTOIS, YEHUDA HOFFMAN, AND DANIEL POMAREDE

billion light-years

11

11.25



Everything astronomers have learned points to a universe populated by superclusters of galaxies, incredibly long filaments, and colossal voids.

by Liz Kruesi

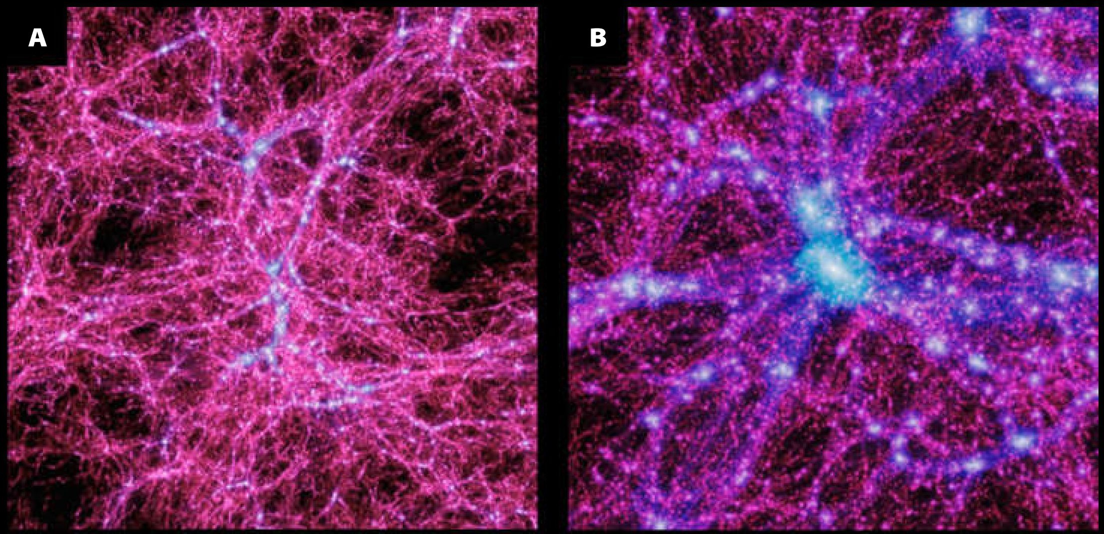
Before extending to what lies in the distant cosmos, scientists must understand our neighborhood. As we've seen, the force of gravity binds the Milky Way and its Local Group neighbors to thousands of other galaxies in the Virgo Supercluster. For decades, astronomers believed that this was the largest gravitationally bound object in which we live.

But a study published in 2014 showed that our home supercluster is just one lobe of a larger grouping called Laniakea, the Hawaiian word for "immense heaven." And although the Virgo Supercluster spans a worthy 100 million light-years, Laniakea has a diameter of more than 500 million light-years.

While distance is an easy value to measure on Earth and even within our solar system, it's much more difficult for locations where no human-made objects have yet explored. Astronomers can't run a tape measure between another galaxy and Earth. Instead, they study a celestial object's light.

In 2009, a group of astrophysicists from five countries ran the Millennium-II Simulation, which created a virtual cube of space 400 million light-years on a side. The researchers then traced the evolution of more than 10 billion "particles," each made up of 6.9 million solar masses of dark matter. These four images, which show a field of view 50 million light-years on a side, zoom forward in time (from A to D) 11.4 billion years.

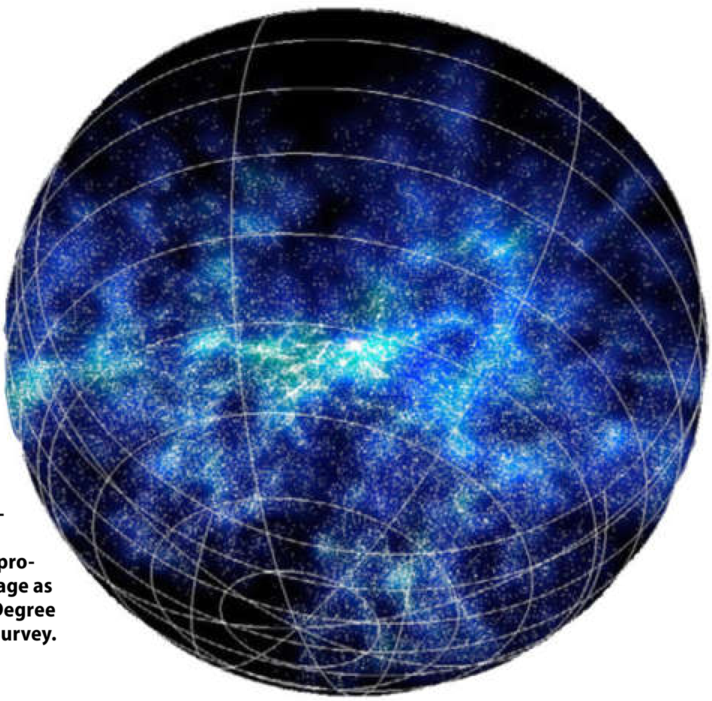
BOYLAN-KOLCHIN, ET AL. (2009)



Measuring the expanse

Scientists have two different methods to compute the distance to a faraway galaxy. The simplest is to use the brightness of the light they collect from it. The University of Lyon's Helene Courtois, one of the researchers who defined the Laniakea Supercluster, likens this method to determining how far away a 60-watt light bulb is. You already know how luminous the bulb is, so once you measure how bright it appears, you can calculate its distance.

Because intervening dust blocks visible light from these galaxies, astronomers look at the strength of radio waves from them to estimate how much energy the galaxies release in visible light. They then compare the intensity of light collected to their calculations of actual energy released to determine the distances to the galaxies.



This map of 125,071 galaxies in the nearby universe shows how they cluster together. Astronomers produced this image as part of the 6 Degree Field Galaxy Survey.

C. FLUKE/6DF SURVEY

The other method of measurement analyzes the light from the brightest galaxies in a cluster to determine how the members it contains are moving. This is a harder process, but it relies on a simple fact: Light can tell scientists about an object's movement toward or away from us. The light's color shifts bluer if the galaxy is moving toward Earth and redder if it's moving away. That movement can arise from the gravitational push and pull of other galaxies or from the expansion of the universe.

We now know that the cosmic fabric is expanding, and it's bringing galaxies along for the ride. Once scientists compare the movements of many objects in the same area of sky, they can break apart the different motions. When mapping galaxies in a supercluster, astronomers focus on the gravitational pull of both visible matter and unseen dark matter.

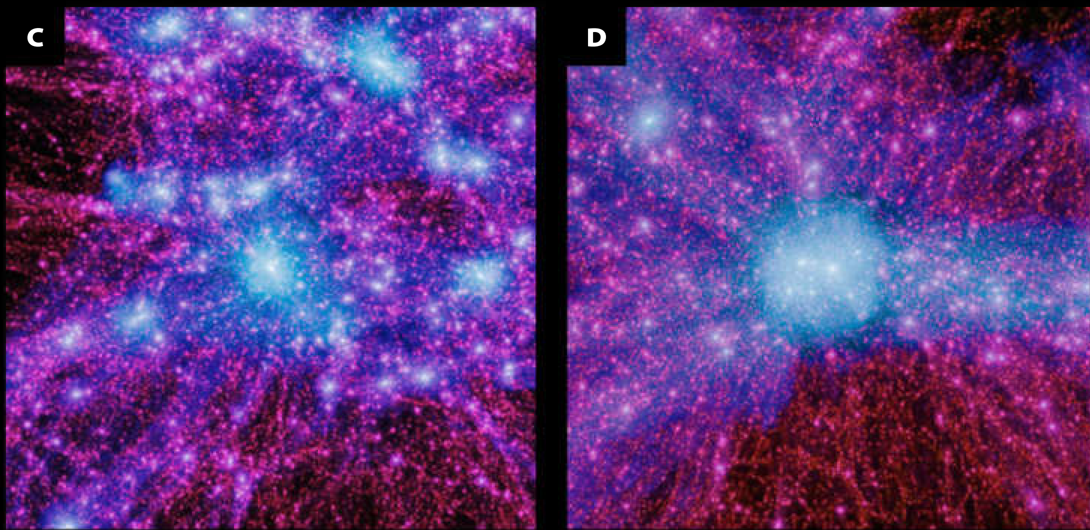
In the Laniakea discovery, Courtois and her colleagues used both methods to study the distances to and the movements of more than 8,100 relatively nearby galaxies. They found the boundaries where some galaxies were moving toward one region and others were moving in another direction. That tipping point, like the top of a hill where a stone can roll toward one valley or another, marks the edge of the Laniakea Supercluster. But what lies farther out?

Filaments and voids

Astronomers began mapping cosmic structure decades ago by analyzing the light from each glowing galaxy using the two previously mentioned techniques. In the late 1970s and early 1980s, a pattern began to emerge: galaxies huddling together with voids in between.

By the late 1980s, astronomers also saw that galaxies near ours are moving toward a specific region

Astronomy Contributing Editor **Liz Kruesi** *writes about pieces of the cosmic puzzle from her home in Austin, Texas.*



of space in the Southern Hemisphere. The force of gravity encourages this movement, which means that this region must contain a huge amount of mass; scientists called it the Great Attractor. All the galaxies in the Laniakea Supercluster are falling toward this spot.

More discoveries followed as astronomers conducted bigger surveys to cover larger areas on the sky. Telescopes and cameras continued to evolve rapidly, and their larger light-grasp and more sensitive detectors allowed scientists to see farther out and further back in time.

Researchers looked at a large-scale view reaching halfway across the universe to determine the distribution of galaxies. They saw that galaxies and their home clusters congregate in clumps connected to other clumps by strings of galaxies, which create seemingly empty voids. This pattern forms the "cosmic web." And it appears to repeat, showing that no location in the universe is more important than any other at the largest scales.

But there's even more material that no telescope can see. The strings of galaxies lie upon a thicker scaffolding of dark matter, a mysterious material that only shows itself through its gravitational interactions with stars and galaxies that we can detect. Dark matter oozes between galaxies in clusters and holds together the strings, or filaments, between superclusters. This universe holds five to six times as much dark matter as normal matter.

Because astronomers can't see dark matter, the bulk of cosmic structure is invisible. To understand what it looks like, scientists build universes in complex computer simulations that compress all of cosmic evolution into mere weeks. They know roughly how much normal matter and how much dark matter the universe has now. They load this information, along with the laws of physics, into the computer model.

"At the end of the simulation, when the virtual universe is mature, we compare it to the observed universe," says Courtois. The computer model reveals more structure than observers detect, a cosmic web stretching back billions of years into cosmic history.

Brilliant signposts

Even the brightest galaxies can't compete with the luminosity of actively dining supermassive black holes. While every large galaxy harbors one such behemoth, only a fraction of them are feeding, a classification that astronomers call "active." A quasar is one type of active galactic nucleus.

The black hole feeds on material like stars or gas clouds that pass too close. As gravity funnels that material toward the high-mass black hole — like water spiraling toward a drain — it forms a disk. The material rubs against itself and glows due to friction. This light is visible across vast distances — so far, in fact, that the light from the nearest quasar has taken 600 million years to reach us.

Astronomers have found quasars scattered across the universe. The most distant one existed just 750 million years after the Big Bang. Its light has traveled for more than 13 billion years to reach us.

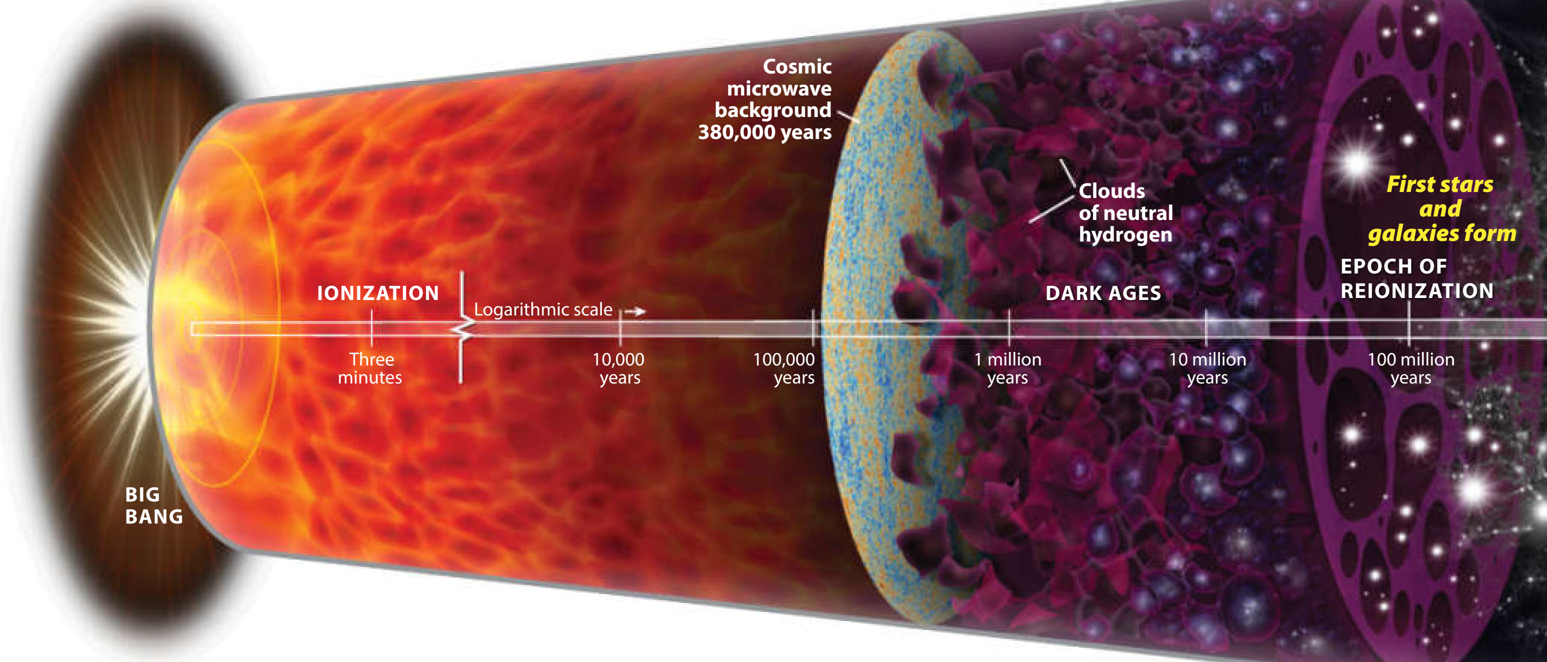
Quasar light is a multiuse tool for studying the distant universe. Scientists can map these objects in the same way they map other galaxies to find structural filaments and voids. Quasars also can act as flashlights to illuminate the gas that lies around their home galaxies, the gas between galaxies, and even the gas falling along nearby filaments.

University of California, Santa Cruz, astronomer J. Xavier Prochaska and colleagues have studied some 20 distant quasars, and they've made two big discoveries. First, they saw a huge clump of hydrogen surrounding a quasar that was much larger than the galaxy should be. They reason this gas lies

THE DIFFICULTY OF DEFINING DISTANCES

The fabric of space-time has been expanding since the universe came into existence 13.82 billion years ago. That expansion ignores the speed limit that governs moving objects — the speed of light. Whereas on Earth (but not just on Earth), nothing can travel faster than light, the cosmic fabric can. That means two spots in our universe that were near each other and could send signals to each other right after the Big Bang have been pulled apart by cosmic expansion to much farther than 13.82 billion light-years distant. In fact, they now lie some 95 billion light-years apart. This topic commonly causes confusion, and it is one reason why when talking about distant galaxies, astronomers state how long the light has been traveling through the cosmos instead of a distance value. — *L. K.*

How it all formed



Astronomers think a span of time that lasted hundreds of millions of years called the reionization era began when the first stars and galaxies emitted radiation that turned hydrogen atoms (one proton, one electron) into hydrogen ions (a proton without an electron). *ASTRONOMY*: ROEN KELLY

VOIDS AREN'T EMPTY

The spaces between galaxies are not empty. Huge reservoirs of hot gas — invisible to human eyes but glowing in X-rays — fill the gaps. And even the large-scale voids in the cosmic web structure aren't vacant. The Cosmic Infrared Background Experiment (CIBER), with its onboard Wide Field Imager (WFI) took four 7-minute rides on sounding rockets between 2009 and 2013. WFI collects near-infrared radiation with two 4.4-inch telescopes. During two of those rides, WFI found a brighter glow in the universe than expected. The scientists involved with CIBER think there are far more stars wandering through the cosmic voids, likely flung from their home galaxies by gravitational interactions. — *L. K.*

along a filament that contains the quasar. Its light has been traveling for nearly 11 billion years.

Second, the researchers recently found four quasars close to one another and embedded in an enormous cloud of hydrogen. "It's a structure that will evolve into something like [the] Virgo [Cluster] today," says Prochaska.

In both discoveries, the light he and his colleagues see comes from fluorescence, he says, "where the quasar shines at a range of energies onto a galaxy and the galaxy actually shines back." Prochaska thinks that with the observing tools set to come online in the next five to 10 years, astronomers will find hundreds of quasars embedded in filaments and forming galaxy clusters.

To the early cosmos

The farther astronomers look from Earth, the less organization they see. That's because they're seeing the cosmos at an earlier stage, and modern-day structures — like spiral galaxies and dense clusters of thousands of galaxies — didn't exist. The universe was not born complex. Instead, after the Big Bang, it was dense and hot, filled with electrons, protons, and light bouncing between those atomic pieces. The cosmos has been expanding since that moment 13.82 billion years ago.

Once it had expanded enough for the temperature throughout the universe to cool to about 4,900° F (3,000 kelvins), each proton grabbed a nearby electron to form a neutral hydrogen atom. With fewer particles floating around, the pinball game was over.

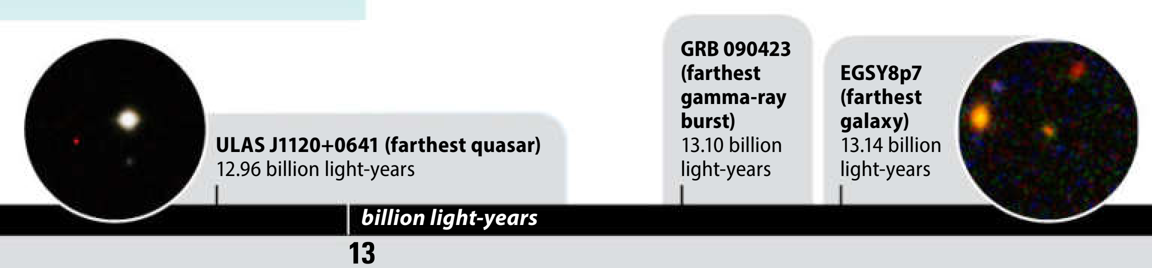
At that point, light was free to stream about the cosmos. That light has been traveling along the fabric of space-time ever since. Today, it bathes the sky in a cool microwave glow, its wavelength stretched by cosmic expansion.

This cosmic microwave background (CMB) looks nearly the same in every direction. It reveals to astronomers what the universe looked like just 380,000 years after the Big Bang: an almost featureless soup of hydrogen and helium.

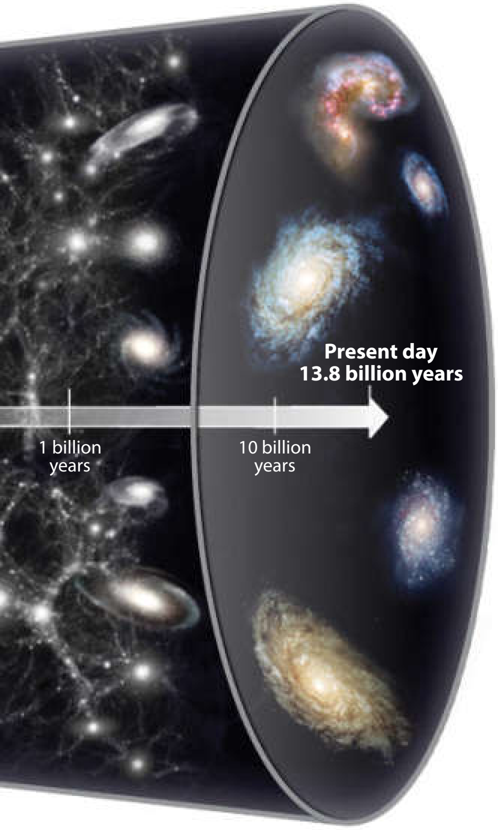
The tiny differences in temperature it contains reflect tiny differences in density. Eventually, those denser areas grew into galaxies and galaxy clusters, while the least dense regions emptied.

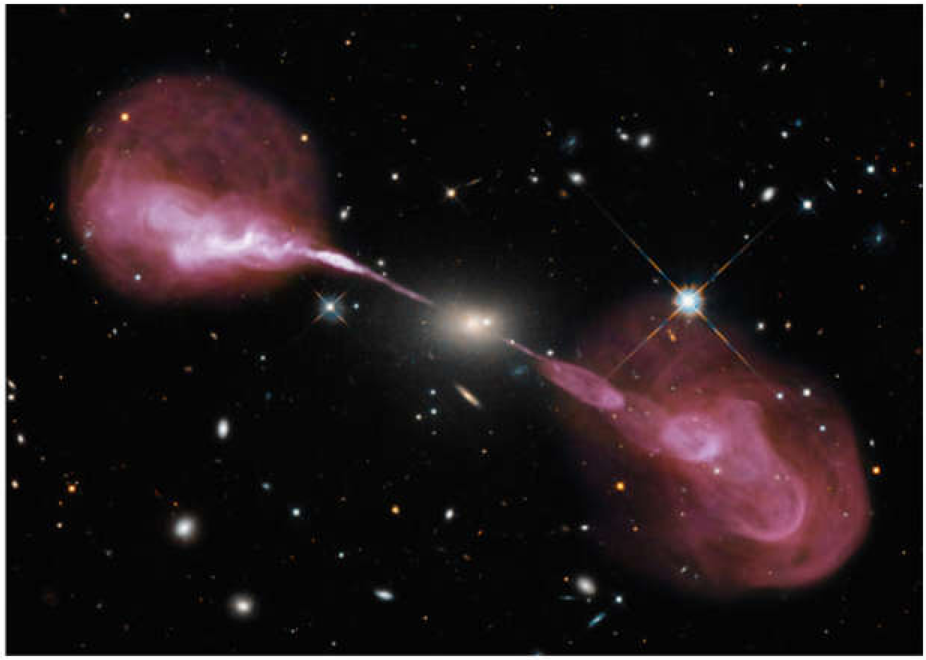
"Understanding that transition, from a simple universe to something with interesting structure in it, is a crucial missing piece in astronomy," says Steve Furlanetto of the University of California, Los Angeles.

This transformation happened in the astronomical Dark



ESO/UKIDSS/SDSS (ULAS J1120+0641); I. LABBÉ (LEIDEN UNIVERSITY)/NASA/ESA/JPL-CALTECH (EGSY8P7); ESA/PLANCK COLLABORATION (CMB)





This image of 3C 348 combines visual data from the Hubble Space Telescope with radio data from the Karl G. Jansky Very Large Array (VLA). Hubble captured the yellowish elliptical galaxy at center. The VLA revealed an active galactic nucleus (AGN) with 1.5-million-light-year-wide jets of high-energy plasma coming from the region of a 2.5-billion-solar-mass black hole. Astronomers use quasars, another type of AGN, to study the distant universe. NASA/ESA/S. BAUM AND C. O'DEA (RIT)/R. PERLEY AND W. COTTON (NRAO/AUI/NSF)/THE HUBBLE HERITAGE TEAM (STScI/AURA)

Ages when material wasn't yet dense enough to form stars, which could light the way. When the first stars and the galaxies they congregated in formed, the overall mix developed into today's cosmos. But the first galaxies, says Furlanetto, were up to a million times smaller than the Milky Way and lie so far away from us that telescopes cannot see them. Instead, astronomers search for these first objects by how they affected material around them.

Finding this intermediate range, which lies between the CMB (380,000 years into the universe's history) and the quasars and galaxies that lived 1 billion years after the Big Bang, revolves around the most prevalent element in the cosmos: hydrogen. As stars and galaxies lit up, they spewed high-energy light. This radiation is powerful enough to knock away the one electron a hydrogen atom contains, creating a hydrogen ion.

Those light sources continued to emit energy, "and then bit by bit, the first sources carved cavities of ionized material," says Saleem Zaroubi of the Kapteyn Astronomical Institute in the Netherlands. These cavities grew while more stars lit up, eventually ionizing all of the neutral hydrogen in their regions of space.

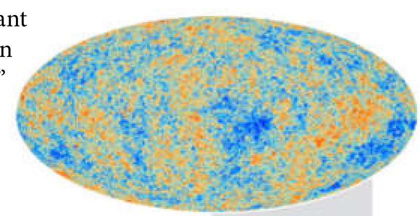
The key to spotting the transition is the prediction, from 1944, that neutral hydrogen can emit radio energy with a wavelength of 21 centimeters. Ionized hydrogen, however, doesn't emit this radiation. Because neutral hydrogen filled the early cosmos, researchers expect there was enough of it to faintly glow as radio waves. This makes for a region nearer to us with no 21-centimeter signal and a stronger radiance farther away.

The search for this radiation — evidence of an epoch astronomers call reionization — has only just begun, and no instrument has picked up this faint glow yet. Radio telescopes with the ability to detect this emission started operating recently, and another will come online in a few years.

Scientists who are on the hunt to map reionization point out that the transition between the neutral, bland universe and the ionized, lumpy universe is a long process — hundreds of millions of years. That is a major missing section along the cosmic distance scale. Zaroubi agrees: "It's an important step in this scientific narrative of the formation of the universe from the beginning until now."

Astronomers have learned an incredible amount about how our universe looks at the largest scales and also what it was like in its infancy. Unfortunately, they still are missing a major chapter in the cosmic story.

Yet the scientists who study reionization, like Zaroubi and Furlanetto, are confident that in the next couple decades observations will uncover the distant radio light that tells the history of how our universe evolved from a neutral bath of hydrogen into the complex web of galaxies, stars, and planets we now call home.



Cosmic microwave background radiation
13.82 billion light-years

Big Bang
13.82 billion light-years

13.5 **13.75**

GATHERING THE DARK

Q: DOES DARK MATTER COLLECT INTO DENSE CONCENTRATIONS LIKE STARS? AND, IF NOT, WHY?

***David White,** Arlington, Massachusetts*

A: This is an excellent question and one that is at the forefront of cosmology research. The short answer is that we do not yet know.

Dark matter particles, being responsive to Newton's laws of gravity, are certainly allowed to clump just like the ordinary matter that is made of protons, neutrons, and other familiar subatomic particles. Dark matter could, therefore, collapse into objects of any size. In fact, there is strong evidence today for the existence of dark matter "halos" — spherical clumps of dark matter centered around every galaxy that extend 10 times larger than the radius spanned by the galaxy's stars.

However, the existence of "compact" dark matter objects, such as stars or planets, is more difficult to ascertain. Ordinary matter has an advantage over dark matter in forming stars or planets because of its electromagnetic interactions, which facilitate collapse into small, compact structures.

Whether dark matter can collapse into these MAssive Compact Halo ObjectS (or MACHOS, as they have been popularly known since the 1980s) is uncertain.

From the theory side, the clumping depends on the exact particle physics properties of dark matter particles, for example, the presence of any non-gravitational interactions between them. In any case, such clumping is certainly allowed in principle.

On the observational side, there exist upper limits on the abundance of MACHOS — made up of either ordinary or dark matter — in our galaxy and the neighboring Andromeda Galaxy (M31). Convincing evidence for the existence of MACHOS made up of dark matter would be incredibly exciting and would provide significant new information in our understanding of dark matter properties.

Dragan Huterer
University of Michigan
Ann Arbor

Astronomers have strong evidence that halos of dark matter surround most galaxies, like the one shown in this simulation. KAVLI INSTITUTE/SIMULATION: HEIDI WU, OLIVER HAHN, RISA WECHSLER; VISUALIZATION: RALF KAEHLER

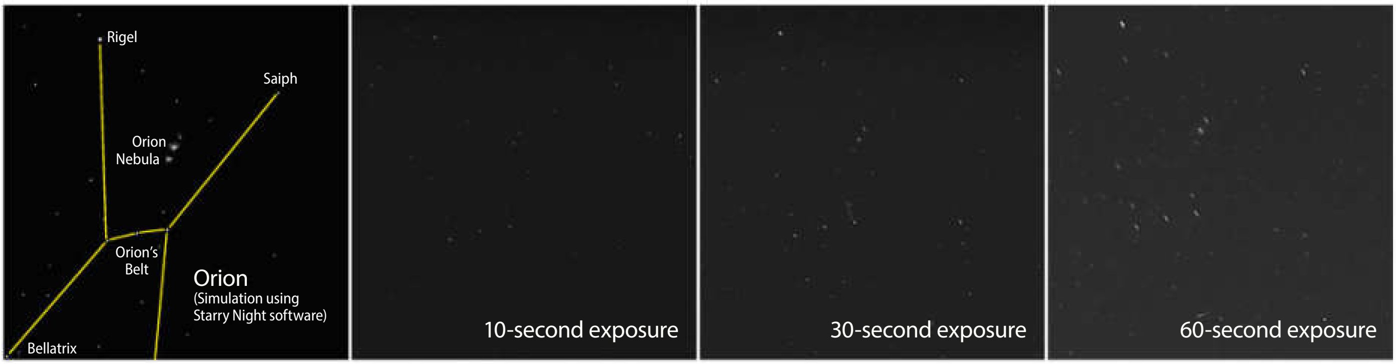
Q: WOULD THE THIN ATMOSPHERE AND ABSENCE OF LIGHT POLLUTION ON MARS MAKE FOR A FANTASTIC NIGHT SKY, OR WOULD MARTIAN DUST/TWILIGHT SPOIL THE VIEW? WHY DON'T WE HAVE BROAD NIGHT-SKY PICTURES?

Dustin Cable
Menlo Park, California

A: Martian astronomy has some advantages. The surface pressure is near 8 millibars — less than 1 percent of Earth's surface pressure — meaning that atmospheric refraction is insignificant. One effect of that is the stars would not twinkle. Another is truly dark night skies. Twilight is sometimes very long, such that astronomical imaging needs to be at least two hours away from sunset or sunrise. But the brightest lights on Mars are Curiosity's Mars Hand Lens Imager's LED lights and ChemCam laser. And in the skies, the moons are much smaller and fainter than ours.

But the dust is a problem, even in the darkest skies. Typically, stars near the zenith lose nearly 1 magnitude due to dust; that increases to 3 to 4 magnitudes at 15° altitude.

The rover cameras have sensitivities similar to the human eye (Opportunity's Pancam can just pick out magnitude 6 or 7 red stars on a clear night, and Curiosity's Mastcam can see magnitude 7 blue stars). That means only the brightest stars are visible at lower altitudes. The cameras' low sensitivity — and the fact that they cannot move while exposing



NASA's Spirit rover turned its panoramic camera skyward above Gusev Crater in 2005 to capture these views of Orion. The famous constellation appears upside down to Earth's Northern Hemisphere viewers because of the rover's southerly path on the Red Planet. NASA/JPL/TEXAS A&M/CORNELL/SSI

— means they can see only the brightest deep-sky objects.

The Andromeda Galaxy (M31) is the farthest object to be (barely) imaged; the Orion Nebula (M42) and the Magellanic Clouds are among the few visible deep-sky-objects. A pan-sky image would require about 150 images — over an hour — and one or two Mars days' worth of the rover's available bandwidth. So, targeted imaging always wins. In the future, perhaps a wide-angle or zoom camera will be able to accomplish a pan-sky image.

Mark Lemmon
Texas A&M University
College Station

Q: SINCE THE DISCOVERY OF THE "PILLARS OF CREATION," WHAT CHANGES HAVE OCCURRED WITHIN THEM AND THE SURROUNDING AREA?

Bobbie Hibbert
Ashton, Idaho

A: The Hubble Space Telescope's iconic image of the Eagle Nebula's "Pillars of Creation" heralded the instrument's rebirth in 1995 and showed the public just how incredible astrophotography could be above Earth's atmosphere. "No one imagined a reaction that would turn the image into a cultural icon," *Astronomy* Contributing Editor Jeff Hester — who actually took the photo — said in April's Hubble commemorative issue. The image has graced everything from U.S. postage stamps to classroom posters.

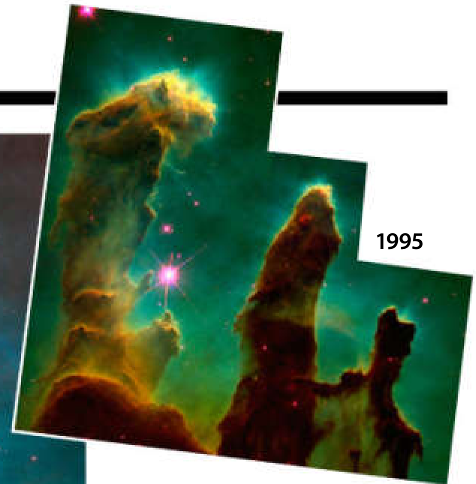
And yet the Pillars of Creation might not even exist anymore. NASA captured this stellar nursery at a fleeting moment. The region is packed with gas and young stars. And as those stars ignite, the gases evaporate into space, as seen in the green streaks that surround the columns. But because the nebula sits some 7,000 light-years from Earth, the light we see left the nebula 7,000 years ago, as agriculture spread across Europe. Intense ultraviolet radiation from young stars has stripped much of the gas since that time.

We're already starting to see the signs of that destruction. NASA revisited the Eagle Nebula last year and this time took images in the near-infrared part of the light spectrum as well as the visible. The view pierced the dust and revealed the pillars' tenuous true nature as well as infant stars hidden among the gas. One prominent jet, perhaps from another forming star, has already increased its reach some 60 billion miles (97 billion kilometers) farther into space. And scientists suspect that a nearby supernova, like the one thought to have brought our solar system radioactive elements, might have already ablated what was left of the gas. Spitzer Space Telescope images show the supernova's shock wave was racing at the pillars 6,000 years ago. We should know for sure in a couple thousand years.

Eric Betz
Associate Editor

Send us your questions

Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P. O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.



By comparing a new image of the Eagle Nebula's "Pillars of Creation" to the original, astronomers are beginning to watch the famous stellar nursery evaporate before their eyes. NASA/ESA/HUBBLE HERITAGE TEAM (STScI/AURA)/J. HESTER, P. SCOWEN (ASU)

Q: CAN YOU EXPLAIN MERCURY'S RETROGRADE MOTION? DO OTHER PLANETS APPEAR TO DO THIS ALSO?

Robert Schneider
Merida, Mexico

A: When astronomers talk about retrograde motion, generally they refer to the apparent motion outer planets make as Earth passes them while orbiting the Sun. Most of the time, all the outer planets appear to move eastward through our sky. During retrograde motion, however, each appears to reverse direction and head westward. Note that this is an apparent motion. The same thing happens when you, in a car, pass another car going in the same direction. While you are passing that car (and because you are traveling faster), it appears to move in the opposite direction.

The two inner planets, Mercury and Venus, don't exhibit retrograde motion for the same reason because they move faster than Earth. So, our planet never passes either of them. Some astronomers, however, define retrograde motion as any westward motion by a planet. For those that agree with that definition, even the inner planets retrograde as they move farther from the Sun (or the horizon) in the eastern morning sky or approach the Sun (horizon) in the western evening sky.

Michael E. Bakich
Senior Editor

OBSERVINGBASICS
BY GLENN CHAPLE

The Mutus X

Seek out this interesting feature of light and shadow a few days after Full Moon.

In response to my August 2013 column, “Elvis and the alphabet,” in which I made reference to the Lunar X, Richard Edmonds of Flagstaff, Arizona, emailed: “You didn’t include an image of the X and I didn’t retain my copy of the September 2012 issue where you featured it and may have included an image. I searched my recent lunar photographs and found this image. Is this the Lunar X to which you refer?”

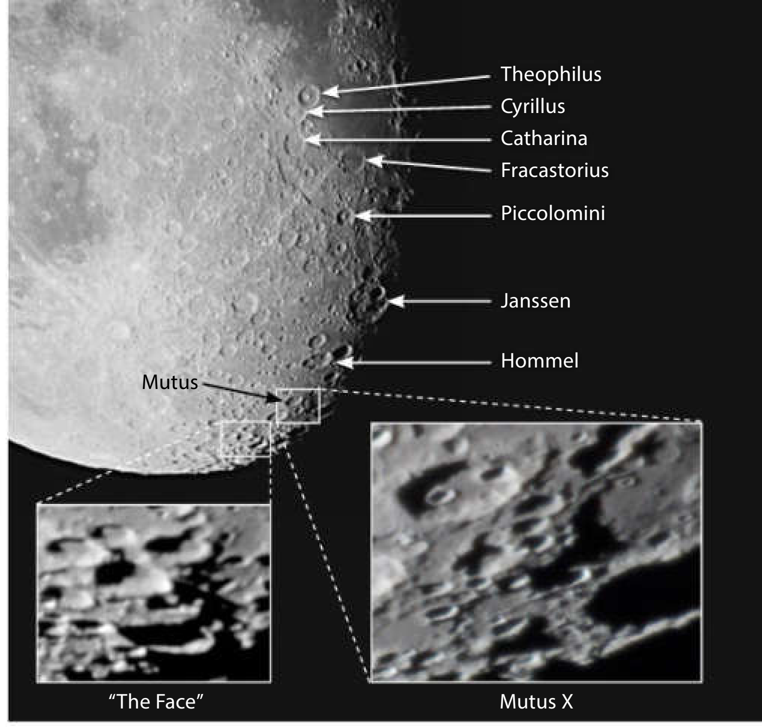
I looked at the image. It wasn’t. The X that I described is the one associated with the crater Werner, located near the lunar meridian about a third of the way up from the lunar south pole and visible for only a few hours around First Quarter Moon. The X that Edmonds found is close to the crater Mutus near the lunar south pole and is observable for several consecutive evenings after Full Moon. He had stumbled upon it while “strolling” around a 19-day-old Moon with a 10-inch Schmidt-Cassegrain telescope and imaging equipment.

Mutus is in an area littered by craters like dimples on a golf ball. To find the Mutus X, I’d need to crater-hop much the way I star-hop when seeking a deep-sky object in a star-rich region. Fortunately, Edmonds had included a whole Moon image that pinpointed its position.

On the evening of September 22, 2013, 4½ days after Full Moon, I tried my luck. Starting with the prominent three-crater chain formed by Theophilus, Cyrillus, and Catharina, I jumped to the crater Fracastorius on the southern shore of the Sea of Nectar and then to Piccolomini farther south. A southeastward jaunt from Piccolomini brought me to the huge crater Janssen and then, with a southward turn, to a crater group surrounding Hommel. Continuing the southerly drift finally brought me to the crater Mutus and, just below it, the X.

Without the chart, I doubt I would have found the Mutus X. Barely half the size of Jupiter’s disk, it was just visible through my 4.5-inch reflector at 150x and still appeared small in a 10-inch reflector at 208x. Its image contorted by atmospheric turbulence, it was indeed a challenge to capture!

After spending a year studying the Mutus X, Edmonds concludes: “It takes an 18- to 19-day-old Moon to really see it. … It seems to result in part from a shadow on the western side of Mutus F [a companion crater to Mutus] and a smaller crater immediately to the north. I would say the X is visible every month but that lunar libration [the Moon’s side-to-side and up-and-down wobble] has a significant effect on the shadowing that can bring out the X in sharp contrast. Several times, even with an active imagination, the X was not recognizable due to libration.”



While searching his images of the Moon for the Lunar X, the photographer came across two interesting features near the crater Mutus. RICHARD EDMONDS

Now it’s your turn to discover the Mutus X. The labeled guide on this page, taken from Edmond’s all-Moon photo, retraces the path I took from Theophilus to the X. Conduct your search a few days after Full Moon when the terminator (the dividing line between night and day on the lunar surface) reaches the eastern edges of the Sea of Tranquillity and the Sea of Nectar. Make the crater-hop with low power, and then switch to high magnification (100x or more).

Once you’ve spotted the Mutus X, be sure to look a little farther south to another interesting feature Edmonds encountered. “By the same strolling method that netted the X,” Edmonds relates, “this guy’s face popped out at me. This one was quite startling considering I was not expecting it. A bit comical when you get used to it.”

This miniature “Man in the Moon” is formed by the craters Simpelius and Simpelius A (the eyes) and Schomberger (the mouth). Between the eyes and mouth, shadows in a small crater create nostrils.

Last July, three days after Full Moon, I checked out the Mutus X and then looked for the face. Even with low magnification, it was easily visible. The smile was wider than that in the image Edmonds sent (shown above), stretching into adjacent Schomberger C and creating a wide troll-like grin. The following night, the mouth was limited to just Schomberger Crater, becoming the silly grin Edmonds had imaged — from troll to droll in a single evening!

His experience leads Edmonds to surmise, “I’m sure there are other real and imaginary objects to be found on the Moon.” There are! As the terminator drifts east to west across our satellite’s surface, dozens of *clair-obscur* (literally, light and shadow) features come and go. For an extensive list, log on to www.the-moon.wikispaces.com/clair-obscur.

Questions, comments, or suggestions? Email me at gchaple@hotmail.com. Next month: The LVAS Observer’s Challenge! Clear skies!

FROM OUR INBOX

Corrections

On p. 47 in the August issue, the Big Bear Solar Observatory was incorrectly cited as closing in 2017. Officials say they expect funding to continue for the foreseeable future.
***— Astronomy* Editors**

On p. 58 in the August issue, “8 Metis” should be “9 Metis” under the illustration. ***— Astronomy* Editors**

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BY KARRI FERRON

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50 Weirdest Objects

Cosmic oddities with Bob Berman

Whether relatively close to home or billions of light-years from us, the cosmos is filled with weird and wacky wonders. After all, as Contributing Editor Bob Berman aptly demonstrates each month in *Astronomy*, we really do live in a strange universe. And for the past year, magazine subscribers have been able to follow Berman's countdown of the 50 strangest and most fascinating oddities he's come to know over the years. Each week at **www.Astronomy.com/50weirdest**, Berman has covered a new object he believes should be inducted into the "Cosmic Hall of Weird," starting at No. 50 and counting down. No. 1 will be revealed by New Year's Eve. What will it be?

Magazine subscribers can still look back on the countdown at **www.Astronomy.com/50weirdest**, getting to tour everything from the coldest place in space and some planetary wannabes to invisible particles and dark galaxies. Be sure to follow *Astronomy* on Facebook and Twitter for updates on when we publish the top five objects (along with lots of other fun stuff). But remember, the online version of Bob Berman's *50 Weirdest Objects in the Cosmos* is only available to magazine subscribers. Join the final weeks of the countdown and receive in-depth articles and tips delivered direct to your door as well as other great online features by subscribing to *Astronomy*. Just visit **www.Astronomy.com/subscribe**.

OBSERVING TOOLS

The Sky this Week

This daily digest of celestial events highlights the brightest objects you can observe each night. In 10-day increments, learn when and where to spot each planet, the best meteor showers, bright comets and asteroids, notable constellations and asterisms, a few deep-sky objects, and more. Each daily entry offers essential details of the event or object and how to locate it in your sky. See what's happening tonight at **www.Astronomy.com/skythisweek**.

COMMUNITY

Reader Photo Gallery

Browse thousands of beautiful astroimages like this one of the Owl Cluster (NGC 457) by Jaspal Chadha. Submit your own images at **www.Astronomy.com/readergallery**.

Dave's Universe blog

Astronomy Editor David J. Eicher shares amazing astrophotos, highlights from trips, insights from popular names in the world of amateur astronomy, videos about his favorite topics or a recent scientific pet peeve, and much more at **www.Astronomy.com/davesuniverse**.

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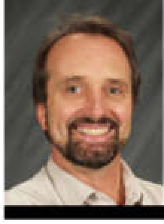

SECRET**SKY**

BY STEPHEN JAMES O'MEARA

Out-of-focus observing

Sometimes, a slightly fuzzy view can help you.

Obtaining a sharp focus is critical to many aspects of amateur astronomy. Ironically, however, placing the object of attention purposefully out of focus can help us make better sense or more accurate observations of what we see. Let's look at some examples.

Star color

The surfaces of stars radiate at different temperatures, which to our eyes appear as different colors: Blue stars are hot; red stars are cool; yellow-white stars (like our Sun) are in between. If you view a star in focus, its color can be difficult to pin down. It can change in a matter of milliseconds because of the refractive effects of our ever-moving atmosphere. When it does, it displays an array of prismatic colors as it scintillates (twinkles) like a diamond under light.

Viewing the same star at high power and slightly out of focus averages out the scintillation, leaving us with a good representation of the star's true color. This method helps especially in double star observing; just be sure not to rack the stars so far out of focus that the disks overlap.

Variable star brightness

Observers often try to estimate the brightnesses of variable stars (those that change in brightness). To do this, they use comparison stars that lie nearby (or better yet, in the same field of view). Sometimes, it's hard to judge the brightness of faint variables.

One way to improve your accuracy is to keep racking the variable out of focus until either it or a similarly bright comparison star disappears. The first one to vanish from view is the fainter of the two; if, however, they disappear simultaneously, you won't have to repeat the process with another comparison star.

To estimate the brightness of an object like Comet PANSTARRS (C/2012 K1), ignore its tails and memorize the size and brightness of the greenish coma. Then, compare the comet's in-focus image with a similar size out-of-focus star image. When the star's fuzzy image equals the comet's sharp one, their magnitudes will be the same. GERALD RHEMANN

Comet brightness

Amateur astronomers use two different acceptable methods to accurately determine the brightness of a comet that sports a significant coma. The first is the Vsekhsvyatskij-Steavenson-Sidgwick method, where you compare a memorized in-focus image of the comet to a defocused image of a comparison star.

The second is the O'Meara-Morris method, where you defocus the stars more than the comet. This yields a more correct surface brightness for the images of both the comet and star. See http://www.icq.eps.harvard.edu/ICQMM.html for more details.

Cluster patterns

Do you enjoy drawing deep-sky objects, especially fanciful open star clusters? One way to enhance patterns of stars within them is to slightly defocus the view. Doing so blends the light of individual points and reveals the most pronounced stellar groupings and intervening voids more distinctly.

Dark nebulae

Although they can look inky black and dramatic in images, dark nebulae can be difficult to detect visually if they don't appear against a bright region of Milky Way. So, if the nebula winds through star fields interlaced with regions devoid of bright stars, you might lose the dark nebula among the weblike confusion.

The remedy is to slightly defocus the Milky Way until it appears as a smooth background glow. Against it, the size and shape of the dark nebula will stand out.

It also helps to focus your attention on the darkness rather than the light. You may think it odd, but "telling" your eyes what to see can help you focus on your target in the out-of-focus field.

As always, please send your thoughts related to my column to sjomeara31@gmail.com.

COSMIC WORLD

A look at the best and the worst that astronomy and space science have to offer. **by Eric Betz**

Cold as space ← → Supernova hot

What's in a name?

The International Astronomical Union (IAU) announces new publicly chosen nicknames for dozens of exoplanets. Of course, by IAU rules none of the planets are actually planets since they don't "orbit the Sun."

Alien ant farm

Stephen Hawking throws support to the Breakthrough Initiatives' E.T. hunt, despite his belief advanced aliens could crush us like humans stomping on an anthill. Out of a billion Earths, surely we're not the only jerks.

Space salad

NASA astronauts Scott Kelly and Kjell Lindgren eat the first food ever grown on the International Space Station — lettuce. Up next: potatoes, which every astronaut knows are vital for surviving on Mars.

Reboot the suit

The Smithsonian raises $700,000 to reboot Neil Armstrong's suit for display after Apollo 11's 50th anniversary in 2019. As a stretch goal, they rehab a lunar module and reboot the space program.

ESO/M. KORNMESSER/N. RISINGER (SKYSURVEY.ORG) (WHAT'S IN A NAME?); NRAO/AUI (ALIEN ANT FARM); NASA/GIOIA MASSA (SPACE SALAD); NASA (REBOOT THE SUIT)

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18.2mm eyepiece

Tele Vue Optics
Chester, New York

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[w] www.televue.com

Camera

MallinCam, Ottawa, Canada

MallinCam's SkyRaider-G Guider-Imager contains an Aptina ARO130 CMOS sensor, which offers 1280x960 resolution. The package includes a 1¼" adapter, a 16-foot (5 meters) USB cable, and an ST-4 guiding cable. The camera weighs 2.15 ounces (61 grams) and is 2.5 inches (64 millimeters) long.

Price: $199.99
[t] 613.749.7592
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Orion Telescopes & Binoculars
Watsonville, California

Orion's 6-Slot 2" Filter Slider holds up to six 2" filters. To change filters, simply push the slider gently until the desired filter clicks into place. You also can adjust the tension of the slider mechanism. Orion includes six 1¼" step-down adapters so you can use that size filter, too.

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Mount

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Vixen's Advanced Polaris Photoguider mount comes with the Star Book One controller, which features variable tracking and slewing speeds as well as backlash compensation. The hand controller is autoguider-ready for astrophotography. Vixen includes the new Polar Alignment Scope with this mount.

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COSMIC**IMAGING**

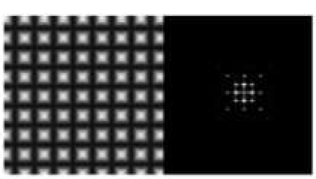
BY ADAM BLOCK

Understanding wavelets

Representing images in ways other than pixels allows for powerful processing. This subject, based on signal processing, requires a mathematical fluency to understand the concepts fully. Many software programs include tools such as fast-Fourier transform filters and wavelet-based filters. Luckily we don't need to derive the math to understand how to use these utilities. However, some background information can make parameters a bit more understandable.

We can deconstruct images as the sum of periodic variations of brightness and represent the frequencies we get by sine and cosine functions. This process is a Fourier transform. In fact, you can represent images by transforming them from brightness at any pixel position to a frequency with a particular amplitude.

Image #1 shows an example for a repeating pattern. In this domain, just a few dots characterize the image. If you modify one of the dots by, say, erasing it (making it black) and transform back to the original image, you'll remove the signal that repeats at that frequency. Note, however, that this modification will affect all structures because functions that model the image are infinite and range the whole image.



ALL IMAGES: ADAM BLOCK

Image #1. In this repeating pattern, the dots represent the frequency values of the variation in the original image.

Wavelets get around this restriction because these functions have shapes that limit their oscillations. You can create a new image in a wavelet domain instead of the strict frequency domain by using these shapes.

The wavelet domain can isolate structures by their sizes. So when you use a "Wavelet Transform," the image deconstructs using the same wavelet function at different scales, rather than the same sine wave at different frequencies.

Using a particular wavelet function, I've broken an image of the Lagoon Nebula (M8) into small-scale features around four pixels in size, large-scale features 32 pixels in size, and a residual image that is everything else (Image #2). Adding these "layers" back together gives me my original image. But now I can modify any layer to enhance or diminish the information there.

PixInsight software has a "Wavelet Transform" tool (Image #3) with many parameters. The "Scaling Function" is the wavelet function you select from the pull-down menu in the form of a kernel filter (the discrete representation of a wavelet). You choose how many layers (scale sizes) to deconstruct the image into.

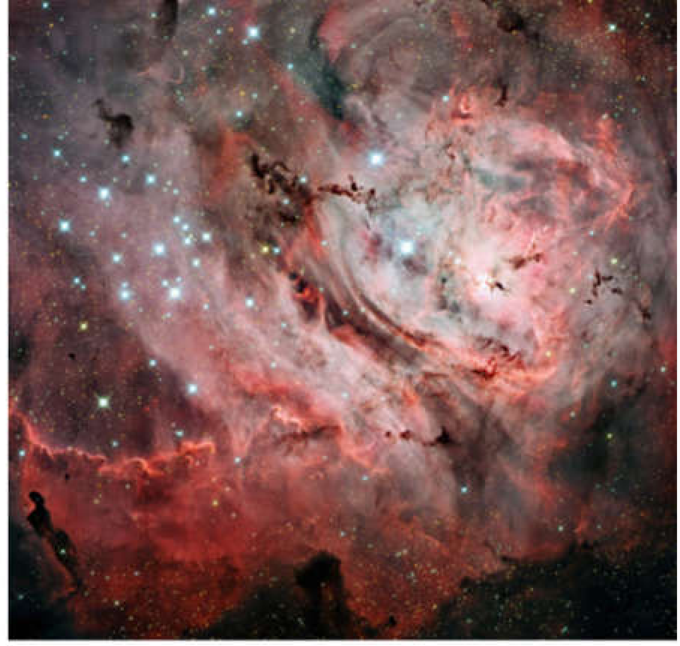


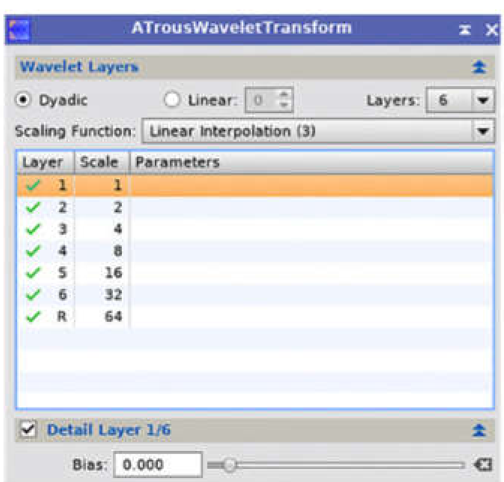
Image #2. The author deconstructed this image of the Lagoon Nebula (M8) using wavelets. It contains layers that correspond to four pixels, 32 pixels, and all residual pixels. You'll find this image online at http://skycenter.arizona.edu/gallery/Nebulae/M8_32in.

You can set the layers up as a doubling scheme (a scale of one pixel for the first, two for the second, etc.). Turning off (removing) the first layer and combining the remaining ones will remove features on the order of one pixel in size. This example shows how you might remove noise in your image.

Changing the "Bias" of a layer gives it more or less weight in the reconstruction, which makes information at a particular scale size more or less obvious. To de-emphasize an image's small stars, just decrease that layer's weight.

Another popular program that uses wavelets for planetary processing is RegiStax. The layer adjustments are similar with the sliders being like the "Bias" setting in PixInsight. In fact, here's a secret many of the top planetary imagers know: They modify the wavelet (filter kernel) and increase the weight of the center of the matrix (Image #4). Changing the shape of the wavelet in this way (making it more "peaked") better probes small features when you adjust the scale size.

In my next column, I'll show you how I used wavelet layers in combination with high dynamic range processing to handle the M8 image.



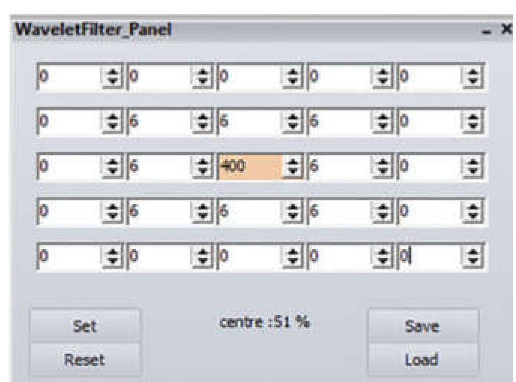


Image #3. This screen shot shows PixInsight's "Wavelet Transform" tool.

Image #4. This screen shot from RegiStax shows the screen that allows you to modify wavelets.

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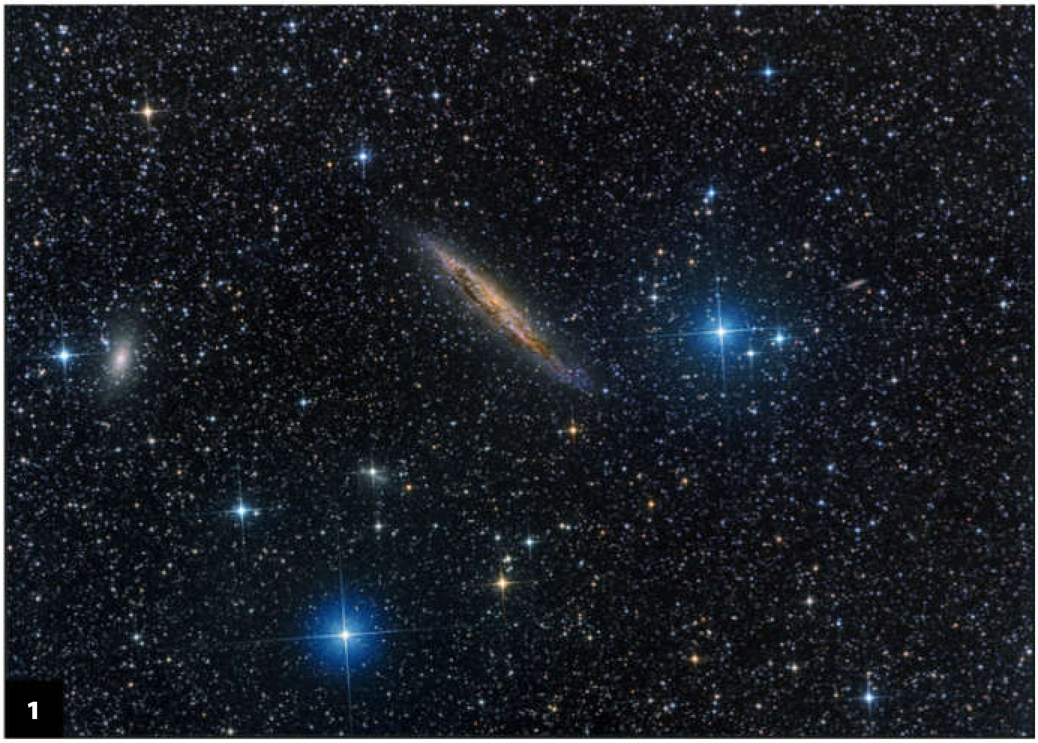
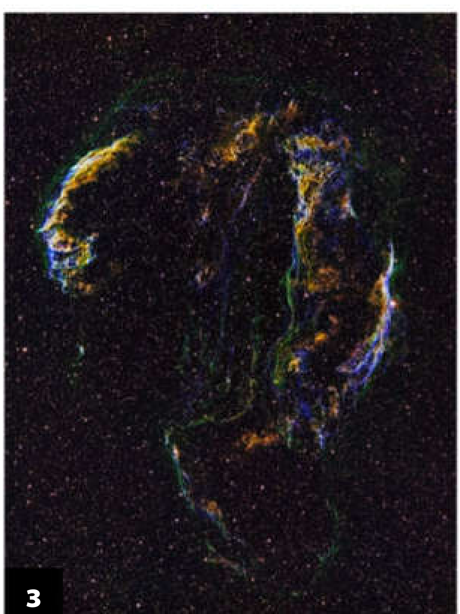


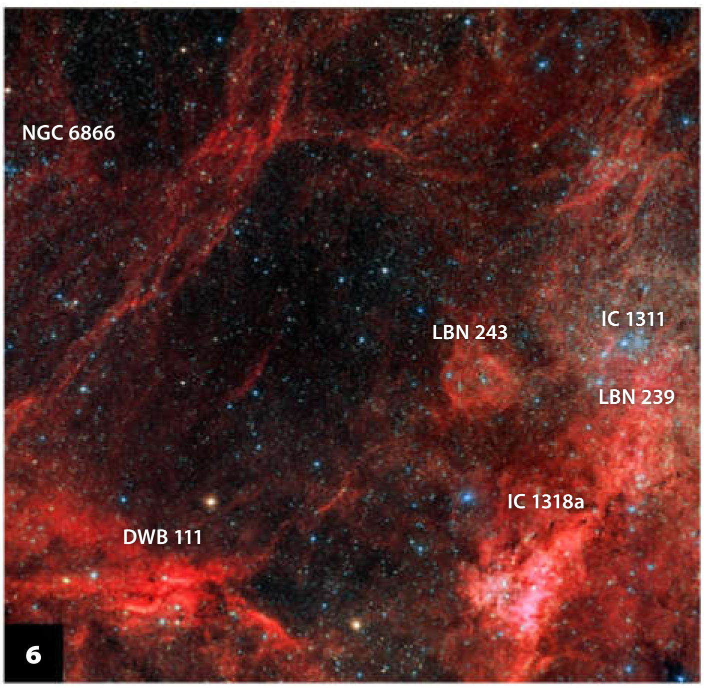
1. SWEET SPIRAL
NGC 4945, also known as Caldwell 83, is an edge-on spiral galaxy in the constellation Centaurus. It shines at magnitude 8.8 and lies some 12 million light-years away. (16-inch Dream Telescopes astrograph at f/3.75, Apogee Alta U16M CCD camera, LRGB image with exposures of 70, 18, 18, and 18 minutes, respectively) • ***Kfir Simon***

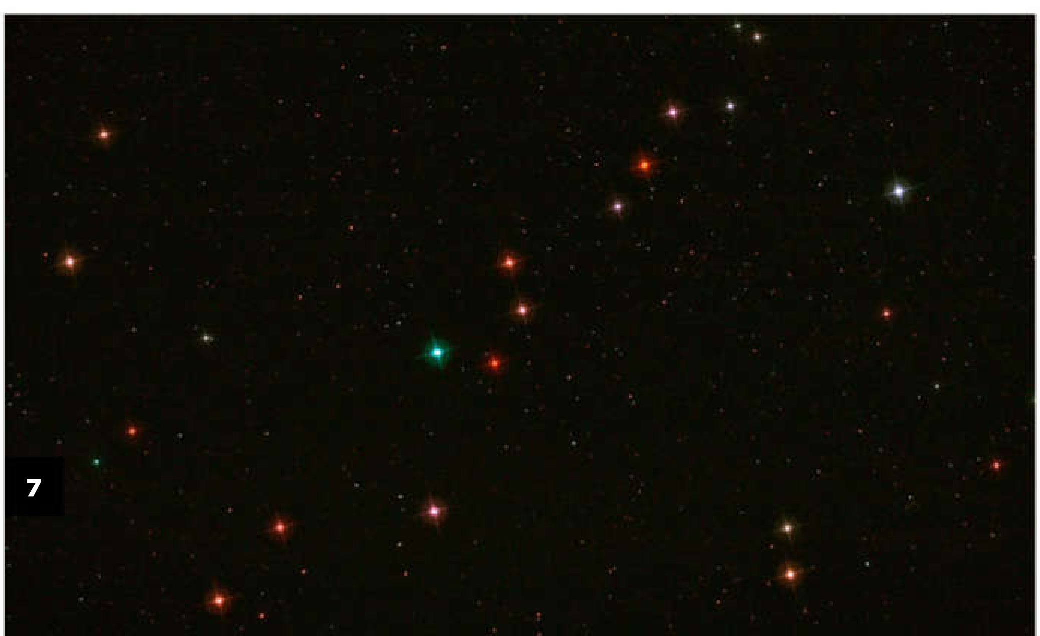
2. CHANGING FACE
From July 25 to August 8, 2015, Venus showed rapid changes. The planet's phase dropped from 12.9 percent (left) to 2.6 percent, and its apparent size increased from 47.6" (left) to 56.2". (14-inch Celestron Schmidt-Cassegrain telescope, ZW Optical ASI174MM CCD camera) • ***Pete Lawrence***

3. LOOP DE LOOP
The so-called Cygnus Loop is a supernova remnant. It contains many individual sections designated by names and numbers, including those in the Veil Nebula complex. The entire loop has an apparent diameter of 3°. (Quantum Scientific Instruments 683ws-8 CCD camera, 200mm Canon L II f/2.8 lens set at f/4, Hα/OIII/SII image with 4 hours and 20 minutes of exposures) • ***Richard S. Wright Jr.***

4. MOST TRANQUIL
The compact grouping of the Moon, Venus (the brighter of the two points below the Moon), and Mars on February 21, 2015, was hidden behind clouds, which dumped about 16 inches (40 centimeters) of snow on the area around Dagyenice Reservoir near Bursa, Turkey, but thankfully for the photographer the next evening was clear. (Canon 6D, 24mm f/1.4 lens set at f/3.2, ISO 400, 2-second exposure, taken February 22, 2015) • ***Tunç Tezel***







5. GLORIOUS GLOB
M30 is a magnitude 6.9 globular cluster that lies in Capricornus the Sea Goat. It orbits our galaxy within a halo region some 27,000 light-years away. The bright star to its left is magnitude 5.2 SAO 190559. (3.6-inch Astro-Tech AT90EDT refractor at f/6.7, SBIG ST-8300M CCD camera, LRGB image with exposures of 120, 40, 40, and 40 minutes, respectively) • ***Dan Crowson***

6. SPACE GAS
The region near the star Sadr (Gamma [γ] Cygni) boasts glowing hydrogen clouds, most notably the Butterfly Nebula (LBN 239 and LBN 251) and the Propeller Nebula (DWB 111). (7.2-inch Takahashi E-180 astrograph at f/2.8, QHY CCD QHY11S CCD camera, HαLRGB image with a total exposure time of 4 hours) • ***Terry Hancock***

7. CHASING A WATERFALL
You'll find the asterism observers call Kemble's Cascade in one of the sky's faintest constellations, Camelopardalis. It lies between Cassiopeia and Polaris (Alpha [α] Ursae Minoris). The two dozen stars in this string stretch 2.5° and range from 5th to 9th magnitude. (5.5-inch Newtonian reflector at f/5, Canon Rebel XSi, ISO 800, 5-minute exposure) • ***John Chumack***

Send your images to:
Astronomy Reader Gallery, P. O. Box 1612, Waukesha, WI 53187. Please include the date and location of the image and complete photo data: telescope, camera, filters, and exposures. Submit images by email to readergallery@astronomy.com.

BREAK THROUGH

The Owl and the Snake

One of the sky's brightest planetary nebulae — the Owl Nebula (M97) in Ursa Major — lurks just below the bowl of the Big Dipper. But the southern sky harbors a fainter version of this stealthy predator. The Southern Owl Nebula (ESO 378-1) seen here soars among the stars of Hydra the Water Snake. Like all planetaries, the Southern Owl represents the death throes of a Sun-like star. After the star puffs off its outer layers, its white-hot core energizes the ejected gas and causes it to glow. ESO 378-1 spans nearly four light-years and lies about 3,500 light-years from Earth. ESO

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MARTIN GEORGE describes the solar system's changing landscape as it appears in Earth's southern sky.

February 2016: Bright planets on display

As evening twilight fades in early February, no bright planets grace the sky and observers will have to be content with viewing the glittering summer stars. By late evening, however, brilliant **Jupiter** rises in the east. Now just a month away from opposition and peak visibility, the giant planet gleams at magnitude –2.4 and dominates the overnight hours. Jupiter resides among the background stars of southeastern Leo, on the right end of the upside-down creature where it looks like an extension of the Lion's rear leg.

It's best to wait until the planet climbs higher in the sky around midnight or later if you want to observe it through a telescope. The gas giant world is well worth a look because of the intricate detail in its cloud tops. Even a small instrument reveals an alternating series of bright zones and darker belts that run parallel to the equator. The planet spans 44" at midmonth, almost imperceptibly smaller than its opposition diameter. Also watch for night-to-night changes in the pattern of its four bright Galilean moons.

Nearly three hours after Jupiter rises, ruddy **Mars** pokes above the horizon. The Red Planet travels eastward through the dim constellation Libra the Scales this month, moving toward the head of Scorpius the Scorpion. Mars' strong color makes it easy to identify, but take care not to confuse it with 1st-magnitude Antares, Scorpius' brightest star, which rises somewhat later. The planet shines noticeably brighter than the star, increasing from magnitude 0.8 to 0.3 during February.

Following a year in which Mars appeared so small that it showed little if any detail through a telescope, it is now starting to become attractive. The planet's disk grows from 6.8" to 8.6" across in February and should reveal a few subtle surface markings. Also see if you can detect Mars' phase, which reaches a minimum of 90 percent lit this month.

About 90 minutes after Mars rises, **Saturn** comes into view. The ringed planet inhabits the constellation Ophiuchus the Serpent-bearer, the little-known 13th member of the zodiac. (A nearly 20°-long slice of the ecliptic — the Sun's apparent path across the sky that the planets follow closely — runs through Ophiuchus.) At magnitude 0.5, Saturn shines significantly brighter than anything else in this constellation.

The planet's southerly declination makes it an attractive target for telescope owners, particularly once it climbs high in the east before morning twilight begins. Saturn's disk measures 16" across in mid-February while the rings span 37" and tilt 26° to our line of sight. In moments of good seeing, the dark Cassini Division separating the outer A ring from the brighter B ring should appear obvious even through small scopes. Also look for 8th-magnitude Titan, Saturn's biggest and brightest moon.

The parade of planets continues as the night wears on. Brilliant **Venus** arrives next, cresting above the eastern horizon a bit more than two hours before the Sun. Gleaming at magnitude –3.9, the planet outshines every other celestial object except for the Sun and Moon. Still, the inner world is moving away from Earth and doesn't look like much through a telescope. All you'll see is a 12"-diameter disk that is nearly 90 percent lit.

Mercury has crept away from the Sun and now joins Venus in February's early morning sky. Look for the innermost planet to the lower right of Venus all month. Mercury reaches greatest elongation February 7, when it lies 26° west of the Sun. It then stands 11° high in the east-southeast an hour before sunrise. Coincidentally, the waning crescent Moon appears just to the lower left of Mercury that same morning. Through a telescope, the planet's disk then spans 7" and appears slightly more than half-lit.

The starry sky

As darkness falls on February evenings, Orion the Hunter stands tall in our northern sky. In fact, this is one of the few constellations that appears prominent from both north and south of the equator. If you ignore the Hunter's head, sword, and shield, you can envision him as an upright figure even from the Southern Hemisphere. Picture brilliant blue-white Rigel and Saiph as his shoulders or arms with Bellatrix and ruddy Betelgeuse as his legs.

Of course, things are not that way. From our southern perspective, Orion stands on his head and his sword points upward. People often remark that Orion has a rather small head for such a large body, but it holds a lot of interest for observers. The stars Lambda (λ), Phi^1 (ϕ^1), and Phi^2 (ϕ^2) Orionis form the Hunter's head. They make a small triangle with Lambda at the bottom.

Magnitude 3.4 Lambda Ori is the brightest of the three and has the proper name Meissa, which comes from an Arabic term meaning "The Shining One." Meissa is a fine double star whose components shine at magnitudes 3.6 and 5.5 and are separated by a reasonably close 4.4". Moderately high magnifications split them quite easily.

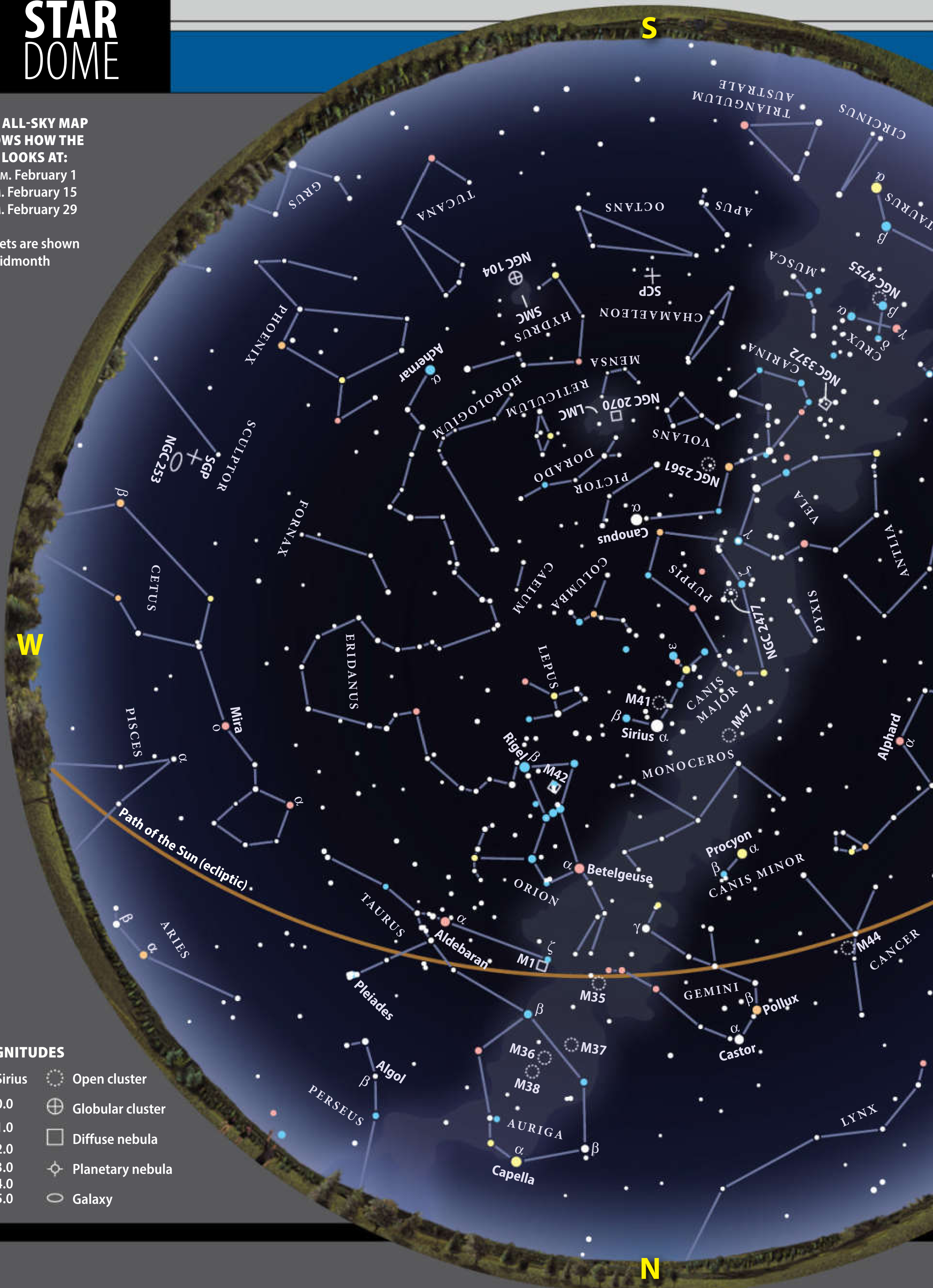
Meissa is also the brightest member of an open star cluster known as Collinder 69, from Swedish astronomer Per Collinder's catalog of 471 open clusters published in 1931. It covers about 1° of sky and shows up best through binoculars or a telescope with a wide field of view.

There is much more to this part of the sky, however. A huge region of faint nebulosity that shows up only on photographs surrounds Lambda. The so-called Lambda Orionis Nebula is a massive cloud of star formation that spans about 10°. American astronomer Stewart Sharpless included it as number 264 in his second catalog of emission nebulae. If we could see this glowing cloud with naked eyes, Orion's head would look a lot bigger.

STAR DOME

THE ALL-SKY MAP SHOWS HOW THE SKY LOOKS AT:
10 P.M. February 1
9 P.M. February 15
8 P.M. February 29

Planets are shown at midmonth



MAGNITUDES

- Sirius
- 0.0
- 1.0
- 2.0
- 3.0
- 4.0
- 5.0

- Open cluster
- Globular cluster
- Diffuse nebula
- Planetary nebula
- Galaxy

HOW TO USE THIS MAP: This map portrays the sky as seen near 30° south latitude. Located inside the border are the four directions: north, south, east, and west. To find stars, hold the map overhead and orient it so a direction label matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

STAR COLORS: Stars' true colors depend on surface temperature. Hot stars glow blue; slightly cooler ones, white; intermediate stars (like the Sun), yellow; followed by orange and, ultimately, red. Fainter stars can't excite our eyes' color receptors, and so appear white without optical aid.

Illustrations by *Astronomy*: Roen Kelly

FEBRUARY 2016

Calendar of events

1 Last Quarter Moon occurs at 3h28m UT

The Moon passes 3° north of Mars, 9h UT

3 The Moon passes 3° north of Saturn, 19h UT

6 The Moon passes 4° north of Venus, 8h UT

The Moon passes 4° north of Mercury, 17h UT

7 Mercury is at greatest western elongation (26°), 1h UT

8 New Moon occurs at 14h39m UT

10 The Moon passes 2° north of Neptune, 0h UT

11 The Moon is at perigee (364,360 kilometers from Earth), 2h41m UT

12 The Moon passes 1.7° south of Uranus, 14h UT

15 First Quarter Moon occurs at 7h46m UT

Asteroid Astraea is at opposition, 12h UT

16 The Moon passes 0.3° north of Aldebaran, 8h UT

22 Full Moon occurs at 18h20m UT

24 The Moon passes 1.7° south of Jupiter, 4h UT

27 The Moon is at apogee (405,383 kilometers from Earth), 3h28m UT

28 Neptune is in conjunction with the Sun, 16h UT

29 The Moon passes 4° north of Mars, 18h UT